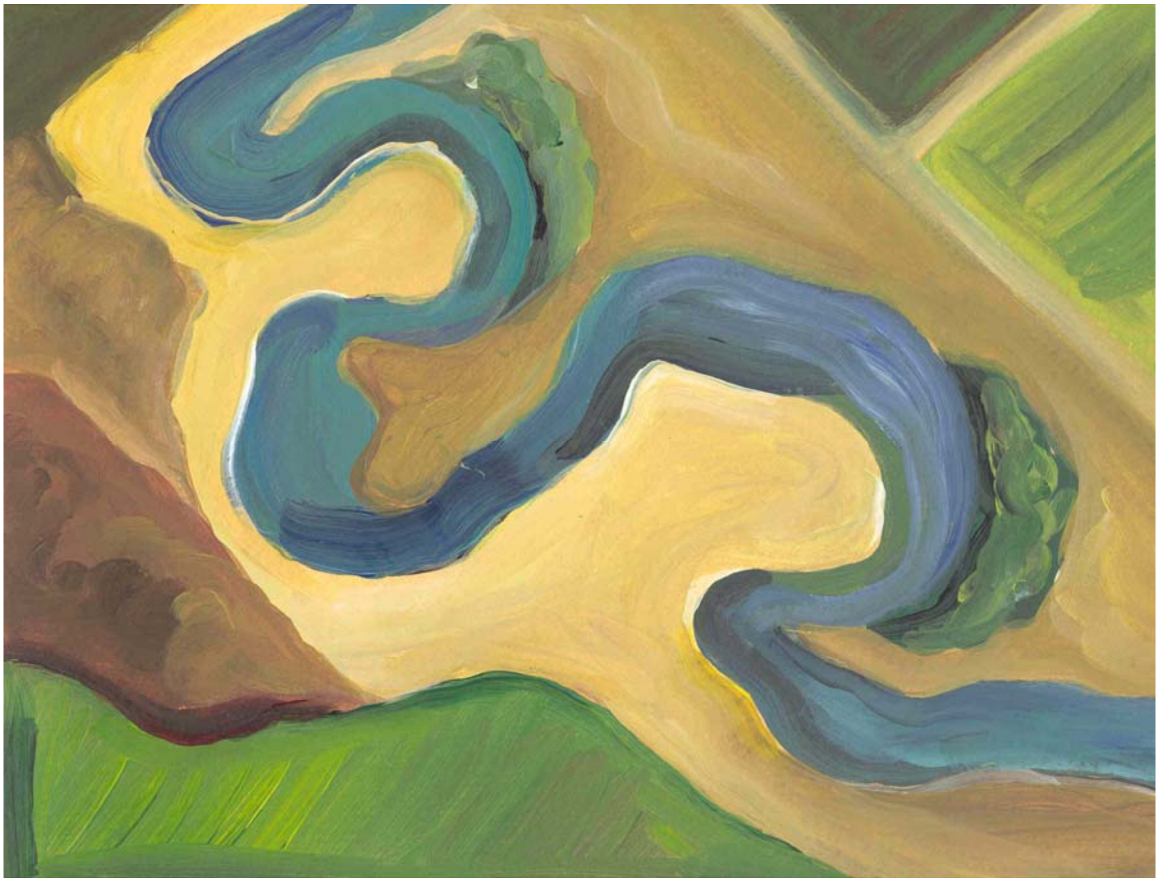
Sonoma Creek Watershed Sediment TMDL and Habitat Enhancement Plan



Preliminary Project Report

California Regional Water Quality Control Board
San Francisco Bay Region

Tina J. Low
July 19, 2007

2007
California Regional Water Quality Control Board, San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

1. Introduction

1.1 Overview

Due to declining native fish populations and evidence of excessive erosion, Sonoma Creek has been officially designated as impaired by sediment since 1996. Staff of the San Francisco Bay Regional Water Quality Control Board (Water Board) propose to address this impairment by amending the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan) to incorporate a Total Maximum Daily Load (TMDL) for sediment and a Habitat Enhancement Plan designed to protect beneficial uses of Sonoma Creek and restore and protect the fishery.

This preliminary project report provides the scientific and technical bases for the project. As we explain below, our approach to developing a Basin Plan amendment will entail: 1) confirming the nature of impairment by identifying significant limiting factors for fish using a limiting factors analysis of Sonoma Creek and its tributaries; 2) evaluating sediment loads and sources; 3) establishing narrative and numeric targets needed to support fish in good condition; and 4) developing an implementation plan to reduce sediment discharges and enhance native fish habitat.

Our purpose in releasing a preliminary report is to provide an opportunity for interested parties to comment, as well as a framework for discussion of implementation actions that may be needed to resolve sediment impairment and enhance native fish habitat in the Sonoma Creek watershed. We anticipate that further discussion with stakeholders and community members will result in an improved and more refined final staff report and implementation plan.

1.2 Compliance with the California Environmental Quality Act (CEQA)

To be included in the final Project Report.

1.3 TMDLs and the TMDL process

The federal Clean Water Act requires states to identify impaired waters and the pollutants causing impairments. The list of impaired water bodies is referred to as the “303(d) list,” referencing section 303(d) of the Clean Water Act. In California, the State

Water Resources Control Board (State Board), with input from the regional Water Boards and stakeholders, adopts the 303(d) list, which is then approved by the U.S. Environmental Protection Agency (EPA).

The Clean Water Act further requires states to address polluted waters by establishing TMDLs for listed pollutant-waterbody combinations. In our state, the regional Water Boards propose and adopt Basin Plan amendments incorporating those TMDLs, and the amendments are then approved by State Board, the state Office of Administrative Law, and EPA.

A TMDL is a water body-specific cleanup or restoration plan that targets the pollutant causing impairment. TMDLs generally include the following elements:

Problem statement	Describes conditions contributing to the water body's designation as impaired
Total maximum daily load (TMDL)	Numeric or narrative expressions of the maximum amount of sediment allowable if the water body is to support its beneficial uses
TMDL targets	Numeric expressions of the desired condition of the water body (protective of beneficial uses). Targets define indicators and associated values necessary to meet numeric or narrative water quality standards.
Pollutant sources	Identifies the causes or contributors of sediment in the watershed
TMDL allocations	Distributes responsibility for sediment reduction. Allocations may be specific to agencies, persons, businesses, or general source category. The sum of allocations must equal the total allowable pollutant level (TMDL).
Implementation plan	Identifies pollution prevention, control, and restoration actions, responsible parties, and schedules related to attainment of water quality standards; enforceable measures; performance standards; and triggers for Water Board action
Monitoring plan	Describes the monitoring strategy that will be used to evaluate TMDL effectiveness, and a schedule for reviewing and (if necessary) revising the TMDL and implementation plan

Additional studies may be prescribed to confirm key assumptions, resolve any uncertainties remaining when the TMDL is adopted, and establish a process for revising the TMDL, as necessary, in the future.

1.4 The Sonoma Creek Sediment TMDL and Habitat Enhancement Plan

For complex watersheds such as Sonoma Creek, where sediment and siltation are associated with adverse impacts to fish spawning, habitat, and migration, reducing sediment inputs will not fully restore the fishery. This is why we intend to combine a sediment TMDL with a comprehensive Habitat Enhancement Plan for the watershed. The Habitat Enhancement Plan will address conditions other than sediment that may have adverse impacts on fish populations, such as barriers to fish migration, lack of complex habitat, and low summer baseflows. The *Napa River Watershed Sediment TMDL and Habitat Enhancement Plan* (SFBRWQCB, 2007) is a detailed example of this two-pronged approach.

The goals of the Sonoma Creek Sediment TMDL and Habitat Enhancement Plan are to:

- Conserve the steelhead trout population
- Enhance the overall health of the native fish community
- Protect and enhance habitat for native aquatic species
- Enhance the aesthetic and recreational values of the river and its tributaries

To achieve these goals, stakeholders in the watershed must work to:

- Reduce sediment loads, and fine sediment in particular, to Sonoma Creek and its tributaries
- Attain and maintain suitable gravel quality in freshwater reaches of Sonoma Creek and its tributaries
- Reduce and prevent channel incision
- Repair large sources of sediment supply (i.e. landslides)
- Enhance channel complexity (i.e., by adding and encouraging retention of large woody debris)

2. Watershed Description

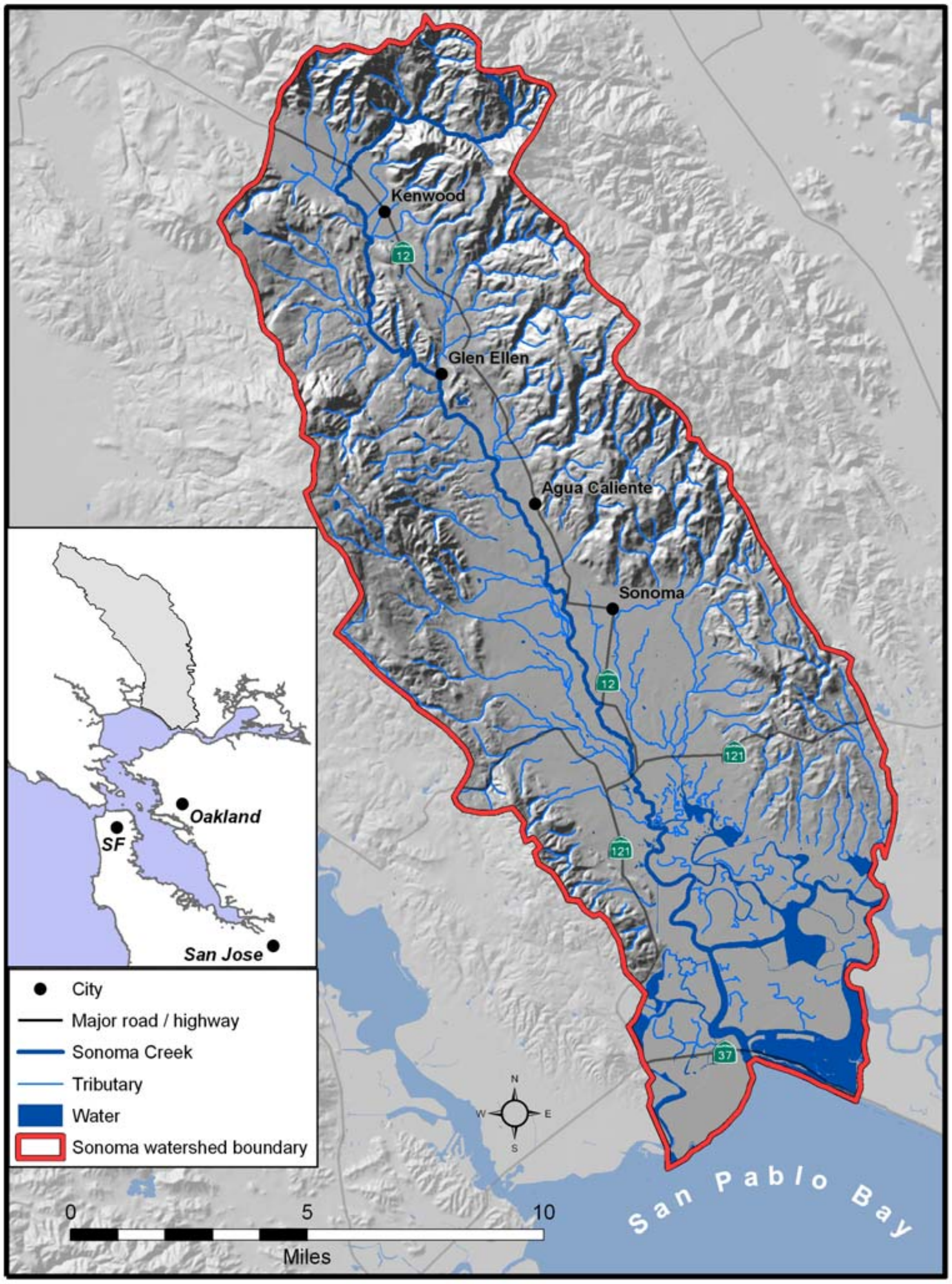
The Sonoma Creek watershed, in California's Coast Range north of San Pablo Bay (Figure 1), covers an area of approximately 166 square miles (430 km^2). The watershed ranges in elevation from sea level to the peak of Bald Mountain (2,739 ft.). It lies in a valley bounded by Sonoma Mountain to the west and the Mayacamas Mountains to the east. The mainstem of Sonoma Creek flows in a southeasterly direction from headwaters on Sugarloaf Ridge through Sonoma Valley before discharging to San Pablo Bay. Numerous tributaries enter the main stem from the mountains that rise on both sides of the valley (SEC et al., 2004). The watershed includes about 465 miles of blue-line streams mapped by the USGS (SEC et al., 2004).

Average rainfall ranges from approximately 23 inches in the lower portions of Sonoma Valley to more than 50 inches on the highest slopes of Sonoma Mountain and the Mayacamas. Most of the rain falls from November through April, with heaviest rainfall occurring from December through February. This rainfall regime results in two distinct seasons in the watershed. During the winter wet season, streamflow and pollutant loading are dominated by precipitation –driven surface runoff. In contrast, groundwater inflow or runoff from human activities dominates streamflow during the dry summer months.

The watershed supports the following Beneficial Uses, as defined in the Basin Plan: cold freshwater habitat, warm freshwater habitat, water contact recreation, noncontact water recreation, fish migration, preservation of rare and endangered species, fish spawning, warm freshwater habitat, and wildlife habitat. It provides habitat for several native species of concern, including steelhead trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), and California freshwater shrimp (*Syncaris pacifica*).

Major land cover types in the watershed are forest (approximately 30 percent), grassland/rangeland (20 percent), agriculture (30 percent—a large and growing portion of this in vineyards), and wetlands and sparsely vegetated land (5 percent). Developed land (residential, industrial, or commercial) accounts for approximately 15 percent of the watershed (ABAG, 2000). Compared to other San Francisco Bay Area streams, the watershed is relatively free of concrete channelization, major flood control projects, and water supply structures (dams). However, historical ditching and draining of the valley floor (see discussion in source analysis that follows) has fundamentally altered the routing of peak flows and sediment in lower Sonoma Creek, with consequent and significant increases in sediment delivery and degradation of aquatic habitat quality.

Figure 1. Location of the Sonoma Creek Watershed



Sonoma Creek is also listed as impaired by nutrients and pathogens. It is likely that actions implemented to reduce sediment loading and enhance habitat will also reduce nutrients and pathogens, and help Sonoma Creek in supporting many of its designated Beneficial Uses.

3. Problem Statement

3.1 Summary

A TMDL problem statement describes the relationships between the identified pollutant, applicable water quality standards, and current water quality conditions in the impaired water body. With regard to the problem of sediment in Sonoma Creek, we find that:

- Populations of steelhead in Sonoma Creek and its tributaries have declined substantially since the 1940's (Leidy et al., 2003).
- Excessive amounts of fine sediment have been deposited in the streambed at potential steelhead spawning sites. Excess fine sediment in the streambed can cause poor incubation conditions for fish eggs, resulting in high mortality prior to emergence. Fine sediment also reduces winter rearing habitat by filling the space between cobbles and boulders.
- Changes in physical habitat structure that appear to be caused by erosion of bed and banks (incision) in Sonoma Creek are resulting in significant adverse changes to steelhead habitat (SEC et al., 2004).
- Sediment discharge and habitat simplification are occurring, in part due to controllable water quality factors.[1]

A detailed discussion of sediment impairment and habitat conditions in Sonoma Creek follows.

3.2 Habitat Conditions

Sonoma Creek supports a diverse assemblage of native fish species including steelhead/rainbow trout, Pacific lamprey, California roach, sculpin, Sacramento sucker, white sturgeon, Sacramento pikeminnow, Chinook salmon, threespine stickleback, prickly sculpin, riffle sculpin, and staghorn sculpin (Leidy, 2007). Chinook salmon are occasionally found in the lower reaches of Sonoma Creek, but their history and the extent of their habitat in Sonoma Creek are not well understood. Coho salmon have been reported in Sonoma Creek but their origin, abundance, and persistence is not known.

Sonoma Creek supported large numbers of steelhead trout until approximately the late 1940s (SEC, 2002). California Department of Fish and Game surveys indicate an overall decline in fish populations over the last century and a half, a period of increasing land use pressures. Historical land uses and practices introduced by early settlers included heavy grazing, timber harvesting, draining wetlands, diverting tributaries, in-stream sand and gravel mining, construction of small dams, and dredging the mainstem of Sonoma Creek (SEC et al., 2004).

[1] As defined in the Basin Plan, controllable water quality factors are those actions, conditions, or circumstances resulting from human activities that may influence the quality of waters of the state and that may be reasonably controlled.

In the late 1800's, many tributaries became directly connected to the mainstem, likely due to more concentrated surface flows, through the creation of ditches (direct alteration), or a combination of these factors. Formerly, in years of normal rainfall, water in the tributaries would sheet-flow onto alluvial fans, and would only flow into the mainstem channel in wetter years.

These and other human practices have increased sediment loads to the creek, reduced vegetation and wood available to stabilize hillslopes and channels, and accelerated flood flows through the stream system.

The decline in the populations of native fishes in Sonoma Creek and its tributaries is summarized in Table 1. This history of the local fish population is based primarily on the Oral History Project prepared by the Sonoma Ecology Center (SEC, 2002) with funding from CALFED.

Table 1. Summary of fishery conditions and land use changes in the Sonoma Creek Watershed

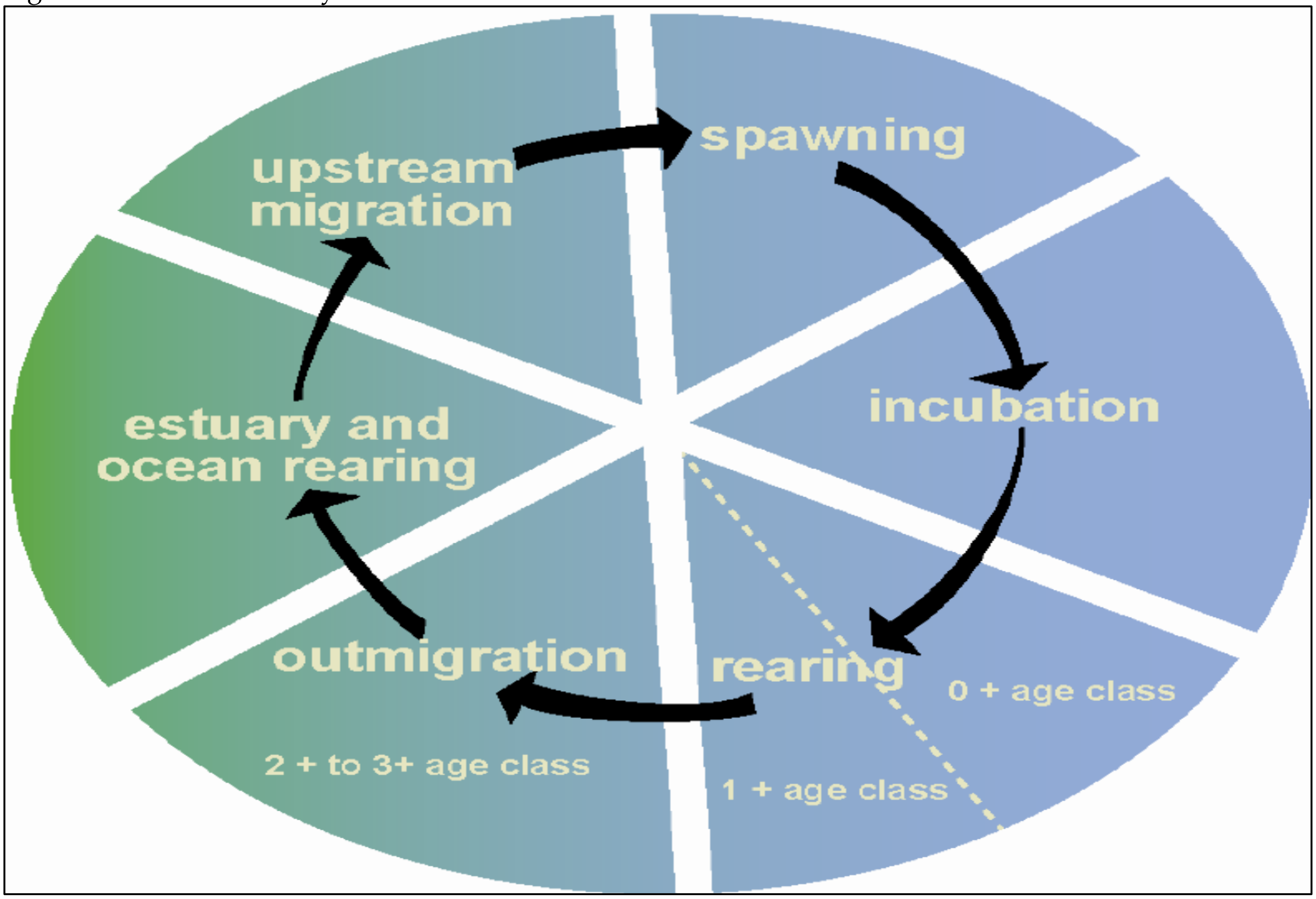
Time Period	Event	Native Fish Populations	Fishing Limit	Land Use changes
1823	Founding of Sonoma Mission	Abundant*	N/A	Beginning of livestock grazing
1856	Old growth redwood logging completed	Abundant	N/A	Extensive cattle grazing
1860 to 1880	Completion of a dam on Graham Creek	Strong evidence of declining fish population 1860 – 1876	N/A	Large scale reclamation of sloughs and saltwater marshes
1880s	Introduction of German carp	Plentiful	N/A	
1890s	Sonoma Creek stocked with trout	Unknown	N/A	Widespread timber harvest by hand equipment
1900s to 1910		Abundant	N/A	Logging Sonoma Mt. by mechanical equipment
1903 to 1920	New regulations and stocking	Possible decline	25 fish	Gravel mining became well established

Time Period	Event	Native Fish Populations	Fishing Limit	Land Use changes
1920s to 1930s		Abundant	25 fish	10,000 acre fire from Mayacamas to El Verano (1923)
Following 1945	End of World War II	Decline	25 fish	
1950s	Reduced allowable fish catch	Decline	10 fish	Last reported logging of redwoods on Sonoma Mt.
1960s	Dam at Larson Park	Decline	10 fish	Increased urbanization – Major fire (1964)
1970s	Major Drought	Serious decline	Closed	Continued intensification of urban and agricultural uses. Construction of Eldridge Dam
1980s	Major decline in steelhead populations	Serious decline	Open	Expansion of hillside agriculture. Removal of Elridge Dam in 1983
1990s	Effort to restore Sonoma Creek	Slight rebound	Closed	Expansion of hillside agriculture

3.3 Salmonid Life Cycle and Water Quality Requirements

Protecting the beneficial uses of Sonoma Creek and its tributaries requires us to understand the salmonid life cycle as well as the habitat and water quality requirements of the watershed's aquatic species. The sediment TMDL and Habitat Enhancement Plan focus on the recovery of salmonid species (particularly steelhead trout) with the intention that efforts to restore and protect this species will benefit all aquatic species in the watershed. The salmonid life cycle can be described in six phases: 1) adult upstream migration; 2) spawning; 3) incubation and fry emergence; 4) juvenile rearing; 5) outmigration; and 6) estuary and ocean rearing. Figure 2 illustrates the salmonid life cycle. The following sections describe each life cycle phase and associated habitat and water quality requirements.

Figure 2. Steelhead Life Cycle



Source: Sonoma Ecology Center, Limiting Factors Analysis (SEC et al., 2004)

Adult Migration

Steelhead return from the ocean to spawn in their freshwater natal stream, usually in their fourth or fifth year (SEC et al., 2004, Appendix A). Steelhead populations are broadly categorized into two reproductive groups, and are commonly considered to be either winter-run or summer run. Steelhead in the Sonoma Creek watershed are winter-run, meaning they enter freshwater spawning streams from fall through spring and spawn a few months later in late winter or spring (SEC et al., 2004, Appendix A).

Ideal habitat conditions for adult migration include deep pools and backwater channels that provide resting opportunities during the arduous upstream migration (SEC et al., 2004). At this stage, the adult fish need enough flow in the stream channel to create adequate depths for passage, generally on the order or one foot or deeper. Adequate depth is often lacking in Sonoma Creek watershed because long reaches of spawning streams dry out during the summer and stay dry until the first fall rains.

Spawning

Once adults have reached their natal streams, they search for suitable spawning gravels where they can build a nest (redd), lay their eggs, fertilize them, and then leave them to incubate and hatch. The availability of suitable spawning gravels is critical to spawning success. Spawning gravels should ideally be relatively free of fine sediment, and contain coarse material (gravel) ranging from the size of a pea to an apple. Spawning gravels should also be of sufficient size and depth (at least one foot square and six inches deep) (SEC et al., 2004). If there are not enough patches of spawning gravel, multiple fish may construct redds on top of each other, destroying the previous redd (SEC et al., 2004; McNeil, 1964).

Egg Incubation and Fry Emergence

Steelhead eggs incubate in the redd for 20 to 100 days; Chinook incubate for 40 to 90 days. The fish hatch from the eggs as alevins still attached to their yolk sacks, and remain in the gravels for another two to five weeks before they emerge as fry. During egg incubation, hatching, and emergence, the fish need an adequate supply of oxygen. The stream flow must have adequate dissolved oxygen, and the redds must be low in fine sediment so that dissolved oxygen can reach the developing fish. Too much fine sediment can clog the redd and smother the developing fish, by preventing the water flow from supplying oxygen and carrying away waste.

Juvenile Rearing

Once the fry have emerged from the stream gravels, they are considered age 0+ fingerlings or juveniles. During this stage, they rear (feed and grow) in freshwater streams and in the estuary before out-migrating to ocean waters. For steelhead, this juvenile rearing stage lasts at least a summer and a winter. Chinook salmon rear for only four to seven months before migrating to the sea. Juveniles that are aged 0-12 months are considered 0+ and those that are aged 12-24 months are considered age 1+. Both Chinook and steelhead require summer rearing habitat, while steelhead also requires winter rearing habitat (SEC et al., 2004).

A complex stream structure is critical for successful juvenile rearing. Juveniles must feed, grow, rest, and evade predators. These activities require diverse habitat conditions, from pools to rest and feed, to in-stream shelter to evade predators. Off-channel pools or sheltering backwater habitats, parts of the stream or floodplain that receive flow from the main channel but are protected from high velocities, provide good rearing opportunities.

Pool habitat is important for both summer and winter rearing. Pools provide resting and feeding opportunities, and are essential in summer as water levels drop. Water temperature is also important, as anadromous fish prefer rearing temperatures in the range of 50 to 55 degrees F. Temperatures exceeding 64-68 degrees F are stressful, and temperatures above 75 degrees F may be lethal. (SEC et al., 2004; Sullivan et al., 2000). Whether temperatures above 75 degrees F are lethal depends on the pre-existing health of the fish, how fast the temperature rises, baseline temperatures before the onset of high temperatures, and how long the high temperatures last. An intact riparian corridor with trees providing shade, as well as cold groundwater inflow, is important for maintaining desired temperatures. With all the challenges facing the juveniles, a large percentage do not survive beyond the first year to reach age 1+.

Outmigration

At the end of the freshwater rearing period, steelhead migrate to the ocean as smolts. Smolting involves a physical transformation that prepares the fish for survival in salt water. Some Sonoma Creek steelhead migrate directly to the sea, while others migrate downstream in the spring and rear in the estuary for an additional year before smolting. Steelhead may migrate at ages 2+, 3+, or less frequently at age 1+. It is more common for age 1+ steelhead to rear an additional year in the estuary than for fish age 2+ or 3+.

During migration, steelhead require sufficient flows and a lack of migration barriers or hazards such was culverts and water diversion structures in their path to the estuary and ocean.

Estuary and Ocean Rearing

Steelhead migrating downstream as juveniles may rear in estuaries for six months to a year before entering the ocean (SEC et al., 2004, Appendix A). Even in cases where juvenile steelhead spend much shorter periods in estuaries, they provide valuable rearing habitat serving to prepare fish for the ocean phase. The majority of steelhead spend one to three years in the ocean, before returning to their natal streams to spawn.

3.5 Limiting Factors Analysis

To improve our understanding of current fish habitat conditions and the significance of sediment pollution relative to other factors (such as temperature, migration barriers, and low summer base-flows) that may be limiting populations of steelhead and salmon, the Water Board provided funding to the Sonoma Ecology Center, in conjunction with Stillwater Sciences and UC Berkeley, to support the Sonoma Creek Limiting Factors Analysis. The goal of the limiting factors analysis was to determine the physical, chemical and biological factors adversely affecting fish populations at all freshwater life stages.

Three aquatic species of concern were evaluated: steelhead trout, Chinook salmon, and California freshwater shrimp. The study focused on steelhead trout, the most common of the three species in the Sonoma Creek watershed and an excellent indicator of overall aquatic ecological health. The focused studies surveyed Sonoma Creek and its tributaries above the tidally influenced reach (north of Schellville).

The limiting factors analysis included several focused studies, including a steelhead census performed in late summer/fall of 2002 (SEC et al., 2004, Appendix B). The steelhead census estimated a total population of 17,000 steelhead trout within the watershed, using snorkel, electrofishing, and extrapolation methods. The size of the measured fish indicate that approximately 90 percent of the population are age 0+ (0-12 months), while only 10 percent are aged 1+ or older. This indicates a "bottleneck" in the local steelhead population during the juvenile rearing stage. The surveys revealed large numbers of age 0+ fish in most pools selected for sampling, but only a few pools held larger (greater than 4.3-inch) age 1+ fish (classified as between 12 and 24 months of age).

The limiting factors analysis estimates that only 10 percent of the age 0+ fish are surviving to the 1+ life stage. Both summer- and winter-rearing habitat for age 1+ fish is very limited in Sonoma Creek due to well-documented changes in creek hydrology and geomorphology. Therefore, increasing the survival of fish ages 12-24 months (age 1+) has the potential to increase the total steelhead population by enhancing rates of smolt out-migration and ensuring that enough fish reach adulthood to maintain a sustainable fishery. Though this TMDL will address water quality and habitat pressures on all steelhead life stages, it will focus on improving habitat and survival for age 1+ juveniles.

Limiting factors found to be adversely affecting fish populations are presented in Table 2, and are discussed below in three categories:

- Sediment-related impairment, which includes impacts resulting from deposition of excess sediment in the stream bed as well as changes in physical habitat structure as a result of bed and bank erosion
- Elevated water temperatures due to lack of shade, loss of deep pools, and low base flow
- Migration barriers and low summer flows

Table 2. Potential Limiting Factors by Salmonid Life Stage

Life Stage	Limiting Factor
Upstream migration	Physical barriers to passage Insufficient flows Migration corridor hazards
Spawning and egg incubation	Spawning gravel mobility Low spawning gravel permeability Redd de-watering High water temperatures Poor water chemistry
Juvenile rearing	Insufficient summer rearing habitat Insufficient winter rearing habitat Poor pool habitat availability Poor pool habitat quality Insufficient in-stream shelter Stranding by low flows Inadequate riparian cover High water temperatures Suspended sediment concentrations Poor water chemistry Low food availability Predation Competition from native species Competition from introduced species
Out-migration	Corridor hazards Inadequate flows High water temperatures Poor water chemistry Predation

Sediment-Related Impairment

Sediment-related impairment includes impacts resulting from excessive amounts of fine sediment deposited in the streambed at potential steelhead spawning sites. These conditions result in low gravel permeability, which can cause poor incubation for fish eggs and high mortality prior to emergence.

In addition to reducing spawning habitat, excess sediment can impact in-stream shelter by filling pools, eliminating deep pool habitat where fish rest and feed. Fine sediment fills the spaces between cobbles and boulders needed for winter rearing habitat. Low-quality shelter for juvenile fish has resulted in increased predation rates and population reductions among of 1+ fish, a critical bottleneck in the steelhead population in Sonoma Creek. Numeric targets will be proposed to reduce impacts of fine sediment.

Some of the most important sediment-related impacts result from changes in sediment transport processes that determine the shape, complexity, and hydrology of stream habitats. Both the direct and indirect effects of human activities adversely affect pool/riffle morphology, channel width, channel bank slopes , and in-stream and riparian vegetation.

Low Gravel Permeability and Pool Filling

Low gravel permeability is a significant adverse effect of excess sediment. Using a simple linear regression relationship, gravel permeability can be used to predict survival-to-emergence. With an average gravel permeability of approximately 2000 cm/hr, fine sediment in Sonoma Creek's spawning gravels causes, on average, 70 percent mortality (30 percent survival) of incubating eggs. (SEC et al., 2004; McCuddin 1977; Taggart 1976; Stillwater Sciences and Dietrich, 2002). This mortality rate is higher than in the neighboring Napa River watershed, where egg mortality is estimated to be 60 percent.

The limiting factors analysis also documented pool-filling by fine sediment, with a watershed average of 8.5 percent (meaning that 8.5 percent of pool volume has been lost due to in-filling by sediment). This watershed-wide average is approximately four times that measured in the Napa River (SEC et al., 2004). Sediment deposition is also reducing winter rearing habitat by filling cobble-boulder bed interstices.

Physical Habitat Structure

*S*tream channel incision has resulted in sediment/flow relationships that promote the creation of deeper and narrower channels. Many stream channels have scoured down to local bedrock, which in some locations consists of weak sedimentary rocks that are easily eroded and yield large amounts of fine sediment. The result is shallower pools, fine sediment deposition from eroding streambeds and destabilized banks, less access to water and soil support for riparian trees, and less in-stream retention of large woody debris and coarse sediments (gravels, cobbles, and boulder for spawning and rearing habitat). Analysis of in-stream shelter in Sonoma Creek yielded ratings ranging from 8 to 86 out of a maximum of 300, using a standard in-shelter index developed by the California Department of Fish and Game. The average watershed-wide score was 38, which is 13 percent of the maximum score. This indicates low quality of shelter for juvenile steelhead (SEC, et al., 2004), as a minimum in-stream shelter score of 80 is recommended for salmonds (CDFG, 1998). Changes in physical habitat structure in Sonoma Creek have caused a decrease in available habitat for fish to hide and rest, particularly during high flows. This can significantly reduce survival of age 1+ fish, as well as total steelhead population numbers.

Suspended Sediment

Suspended sediment concentrations and high turbidity levels may cause moderate impacts on overwintering fish during storms and peak flows. Sonoma Creek monitoring data suggest that the magnitude and duration of suspended sediment concentrations in the water column may at times be severe enough to cause major physiological stress on salmonids (impaired respiration and feeding). Conditions severe enough to cause mortality were not observed during monitored storms.

Staff are currently evaluating whether suspended sediment is impacting beneficial uses. Within a certain range, high suspended sediment concentrations during storm peaks is a natural phenomena that fish are adapted to handle. To determine whether suspended sediment (or turbidity as a surrogate measure) is impacting fish, staff will evaluate whether suspended sediment concentrations remain high for a biologically significantly period of time, after the storm peak. If streams do not clear up following a storm within (on the order of) two days, this would be an indication that suspended sediment is adversely affecting beneficial uses.

Elevated Water Temperatures

During the late summer, cool streamflows are a precious resource for aquatic species. Elevated temperatures can cause chronic stress in fish and reduce growth rates if food supply cannot keep pace with elevated metabolic rates.

Temperature monitoring indicates that although summer stream temperatures stay relatively cool in upper elevation tributaries, temperatures on the mainstem and on Nathanson Creek in the southern portion of the valley can become warm enough—for very short periods—to kill fish (SEC et al., 2004). Increasing riparian cover, pool depths, and groundwater recharge rates in these reaches could help keep temperatures lower to increase likelihood of successful fish rearing.

Low Flows and Migration Barriers

Impacts related to low summer base-flow and migration barriers have a significant affect on steelhead population size.

Summer Low-flow Conditions

Low flow conditions cause significant direct mortality to juvenile fish as rearing pools dry out. Low summer flows significantly affect fish age 1+ (12–24 months), and are a key factor limiting the total steelhead population in Sonoma Creek. Many of Sonoma Creek's tributaries begin to dry up as early as June. Dry reaches may extend as long as five miles by the end of the summer.

The majority of streams affected by seasonal drying cut through alluvial fan deposits. (The largest alluvial fans are found in foothills of the Mayacamas and at the base of the Carriger Creek subwatershed.) In these areas stream beds are surrounded by permeable coarse sediments, and low flows tend to become subsurface flows.

Perennial flows are more common in primarily bedrock stream reaches, such as the mainstem of Sonoma Creek between Glen Ellen and Kenwood, and higher elevation reaches on many tributaries, such as Bear Creek in Sugarloaf Ridge State Park, Calabazas and Hooker creeks, and upper Carriger Creek (SEC et al., 2004).

Barriers to Fish Passage

Man-made barriers to fish passage cut off available spawning and rearing habitat to approximately 25 percent of stream reaches in the Sonoma Creek watershed. Barriers significantly reduce the amount of habitat available to age1+ fish and are important factors limiting the total steelhead population in Sonoma Creek.

Data collected for the limiting factors analysis provide a basis for prioritizing barriers for removal based on upstream habitat (SEC et al., 2004). Restoration goals for in-channel barrier remediation and habitat enhancement features are outlined in the implementation plan.

4. Water Quality Standards

Water quality standards, specified in the Basin Plan (SFBRWQCB, 2006), consist of three components:

- A statement of designated uses for a specified body of water (beneficial uses)
- One or more water quality parameters than can be evaluated to determine whether beneficial uses are protected (water quality objectives)
- An anti-degradation policy, which requires that where water quality is better than needed to protect beneficial uses, those superior water quality conditions must be maintained

Water quality objectives related to sediment and aquatic life and relevant beneficial uses for Sonoma Creek and its tributaries are listed in Table 3. Based on the results of the Sonoma Creek limiting factors analysis (discussed in section 3.5 Limiting Factors Analysis), we conclude that the narrative water quality objectives for sediment, settleable material, and for population and community ecology are not attained, and that these conditions are the result of controllable water quality factors including excessive sediment discharge and related processes.

Staff is currently determining whether the water quality objective for turbidity is attained. The narrative objective for turbidity states is that "Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases from normal background light penetration or turbidity relatable to waste discharge shall not be greater than 10 percent in areas where natural turbidity is greater than 50 NTU." We are not aware of any waste discharges occurring that increase turbidity by more than 10 percent above background or ambient conditions. Suspended sediment monitoring data indicates that turbidity rises to levels stressful to fish following storms and peak flows.

However, turbidity following storms is a natural phenomenon that fish are adapted to handle. In unimpaired streams, we would expect turbidity levels to drop to normal (non-storm) levels, approximately 20 NTU, within a couple of days. This drop in turbidity (or clearing of the water) allows fish to come out of their shelter areas and feed. Extended periods of turbidity would result in loss of feeding opportunities, affecting their growth and survival. We are reviewing suspended sediment data for Sonoma Creek to determine whether turbidity levels remain high for an unacceptable period following storms.

These water quality objectives are not met because human activities have increased the total supply of sediment delivered to Sonoma Creek and caused the supply to be richer in fine sediment. The excess deposits of sediment cause significant harm to the beneficial uses of cold freshwater habitat, wildlife habitat, fish spawning, and the preservation or rare and endangered species. Channel incision harms the physical habitat structure of the creek by reducing the quantity of gravel bars, riffles, and side channels (causing channel simplification); the number and quality of pools; and riparian trees and vegetation. All these impacts threaten steelhead and aquatic wildlife populations. Channel incision is in part a controllable water quality factor that results in a violation of the narrative water quality objective for population and community ecology.

Table 3. Water Quality Objectives and Sediment-Related Beneficial Uses

Water Quality Objectives	Beneficial Uses					
	Cold freshwater habitat	Warm freshwater habitat	Fish spawning	Fish migration	Wildlife habitat	Preservation of rare and endangered species[1]
Turbidity	✓	✓	✓	✓	✓	✓
Sediment	✓	✓	✓	✓	✓	✓
Settleable material	✓	✓	✓	✓	✓	✓
Suspended material	✓	✓	✓	✓	✓	✓
Population and community ecology	✓		✓	✓		✓

Note: Italicized bold text indicates water quality objective is violated.

[1]Preservation of rare and endangered species listed under state or federal law as rare, threatened, or endangered. Steelhead within the Central California Coast, including the Sonoma Creek and its tributaries, are listed as threatened under the federal Endangered Species Act (ESA). California freshwater shrimp have been found in the lower portion of Sonoma Creek. These shrimp are federally listed as endangered species.

Water Quality Objectives:

Turbidity	Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increase from background <10% where natural turbidity is >50 NTU (Nephelometric Turbidity Unit)
Sediment	Should not cause a nuisance or adversely affect beneficial uses
Settleable material	Should not cause a nuisance or adversely affect beneficial uses
Suspended material	Should not cause a nuisance or adversely affect beneficial uses
Population and community ecology	The health and life history characteristics of aquatic organisms in water affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors

5. Numeric Targets and Desired Conditions

A TMDL establishes a desired (target) condition that will attain applicable water quality objectives and protect beneficial uses in the watershed. TMDL targets provide measurable environmental management goals and a clear linkage to attaining applicable water quality objectives.

To protect the cold fishery and wildlife habitat uses of Sonoma Creek, we propose the following numeric target and desired condition: gravel permeability and pool frequency/depth. The *numeric* targets and desired conditions are watershed-specific interpretations of the *narrative* water quality objectives for sediment, settleable material, and population and community ecology (see Table 3)—objectives which are not currently met. These targets and desired conditions (shown in Table 4 and discussed below) relate sediment reductions to the attainment of water quality standards in Sonoma Creek. Attainment of the target/desired conditions (determined by a weight of evidence approach) will constitute attainment of water quality standards.

The two targets were selected based on:

- Relevance to documented sediment-related limiting factors for steelhead
- Direct relationship to sediment-related habitat impacts harming steelhead at the vulnerable "bottleneck" juvenile rearing life stage
- Availability of baseline data

Table 4. Sonoma Creek Sediment Targets

Parameter	Target
Streambed permeability	Greater than or equal to 7,000 cm per hour at potential spawning sites
Pool frequency and depth	Increasing trend in the frequency, distribution, and depth of pools

Water Board staff is evaluating additional habitat parameters and target values to evaluate attainment of water quality objectives for sediment. Additional candidate parameters include streambed scour, percent fine sediment in the streambed, and turbidity.

5.1 Streambed Permeability Target

Streambed permeability (or gravel permeability) refers to the flow rate through the streambed. Permeability is a key factor influencing the survival of incubating salmonid eggs and larvae.

Target

The median value for streambed permeability should be ≥7000 cm per hour at potential salmonid spawning sites in the Sonoma Creek watershed. We estimate this target value corresponds to approximately 50 percent or greater survival of eggs and larvae from spawning to emergence (Stillwater Sciences and Dietrich, 2002).

Background and Rationale

As discussed in the Problem Statement section, incubating fish eggs and young fry need clean, cool water flowing through the redd to provide and replenish dissolved oxygen and to remove metabolic wastes. When a large amount of fine sediment is deposited in the streambed, permeability may be reduced, leading to mortality of incubating salmonid eggs and larvae.

As part of the Limiting Factors Analysis, the Sonoma Ecology Center conducted spawning gravel assessments at 18 potential spawning sites distributed widely throughout the Sonoma Valley (SEC et al., 2004, Appendix G). Using relationships between survival-to-emergence rates and permeability (Stillwater Sciences and Dietrich, 2002; McCuddin 1977; Taggart, 1976), the estimate survival rate (watershed-wide) of eggs and fry is 30 percent. A survival rate of 50 percent has been discussed as a lower threshold (Kondolf, 2000). Increasing gravel permeability will likely also increase the survival rate of fish eggs and fry, and contribute to increased salmonid populations.

In addition, streambed permeability can also be used as an indicator of the amount of fine sediment being deposited.

5.2 Pool Frequency and Depth Target

Pools are very important components of instream salmonid habitat. Pools provide shelter from predators and high flows, cooler water temperatures, and resting and feeding opportunities. In order for a stream to support a sustainable salmonid population, there must be enough pools of adequate depth. In Sonoma Creek, deeper pools are essential summer rearing habitat for juvenile fish, as water levels drop in summer. Pool frequency and depth is partly a function of geology, topography, watershed size, flow, stream disturbance, and pool-forming elements such as boulders and large woody debris (NCRWQCB, 2006).

Target

We propose to establish a TMDL target expressed as an increasing trend in the frequency, distribution, and depth of pools within Sonoma Creek and its tributaries, measured by habitat inventories.

Background and Rationale

Available pool habitat in Sonoma Creek was inventoried by Sonoma Ecology Center is 2001-2002, and by Southern Sonoma Resource Conservation District in 1996 (SEC, 2003; SSRCD, 1996). These habitat inventories showed that existing pool habitat comprises only 10 percent of surveyed streams, as a watershed-wide average. A target of 40 percent pool habitat (40 percent of streams in pool habitat) has been suggested as optimum (NCRWCB, 2006).

In addition, measured pool depths are below optimum. Depth measurement of existing pools ranges from 1 to 2 feet, with an average of 1.25 feet. Age 1+ fish select deeper pools (deeper than 2.5 feet) for rearing.

The limiting factors analysis found that the lack of pool habitat in Sonoma Creek significantly limits the success of salmonids in the watershed. This study suggests that channel incision combined with wood removal has reduced pool habitat, resulting in reduced success in juvenile rearing and smolt production.

Human actions and sediment inputs decrease pool frequency and depth in a number of ways:

- Deposition of sediment directly fills in pools.
- Land use changes and practices increase peak flows and the volume of stream flow, causing channel incision and causing pools to be scoured away.
- Human practices cause the streambed to be higher in fine sediment and thus more easily scoured;
- Direct alteration (filling, straightening) of stream channels in the past has eliminated significant numbers of backwater pools important for over-wintering habitat.

To protect and restore salmonid freshwater habitat, the desired condition for pools is an increasing trend in their frequency, distribution, and depth. It is not possible, given currently available information, to identify a specific number or depth of pools that will be needed to support a cold-water salmonid fishery in the Sonoma Creek watershed. Consistent with the approach outlined in the *Desired Salmonid Freshwater Habitat Conditions for Sediment-Related Indices* (NCRWQB, 2006), we neither expect nor intend for the number and depth of pools to increase beyond the capacity of the waterbody to form pools. An increasing trend desired condition value is established until more information is available. Other TMDLs in California that have utilized this approach include the Scotts River and Garcia River TMDLs (North Coast Region).

6. Source Analysis

This section is based on the Sonoma Creek Watershed Sediment Source Analysis (Sediment Source Analysis)(SEC et al., 2006), completed by the Sonoma Ecology Center in early 2007. This Sediment Source Analysis is currently under review by Water Board staff. The sediment load estimates may be revised as a result of refinements to the methods or assumptions used in the Sediment Source Analysis.

6.1 Overview

The goals of the Source Analysis section are to:

- Estimate the natural background sediment load to Sonoma Creek and its tributaries
- Estimate the sediment load caused by human activities

An important and unique characteristic of this watershed is that the physical stream system is now significantly different from pre-settlement times. As described in the Problem Statement section, many tributaries were historically disconnected from mainstem Sonoma Creek in normal years. Water from the tributaries flowed onto alluvial fans and infiltrated into groundwater. The tributary channels ended in alluvial fans where all of the sand and gravel carried by the stream was deposited, as was some of the fine sediment in the fan and/or natural flood basins located on the valley floor. During higher flows, the tributaries would directly flow into the mainstem. However, European settlers connected many of those tributaries to the mainstem, causing more sediment to be deposited in the creek. The altered condition of the watershed poses a challenge to determining the appropriate sediment load (TMDL) to Sonoma Creek, because while some sediment from tributaries is generated naturally, more sediment is deposited in the creek due to human-caused alteration of the physical stream system (i.e. connection of tributaries to the mainstem).

Table 5 summarizes our estimates of sediment loads to Sonoma Creek, before European settlers connected the tributaries, after those connections were made, and in the year 2005.

We consider naturally generated sediment from formerly disconnected tributaries a “natural background” input because 1) it is possible that Sonoma Creek has adjusted over the last century to be able to assimilate the additional sediment load; 2) removing or significantly reducing this source from Sonoma Creek would require large-scale alteration of current tributaries and re-creation of alluvial fans, actions which are not likely feasible given current land use, political, economic, financial, and landowner conditions; and 3) there is not enough information or certainty that such actions would greatly benefit native fisheries, to justify regulatory actions to address naturally generated sediment sources. This approach is consistent with our strategy in developing the Napa River[2] sediment TMDL.

Table 5. Sediment Delivery to Sonoma Creek (tons/year)

	1800 Pre-Human-Caused Connection	1800 Post-Human-Caused Connection	Current Year 2005 Condition
Natural Processes			
• Channel erosion, Incision	18,000	25,400	25,400
• Landslides	2,600	4,100	4,100
• Soil creep	8,800	17,400	16,600
• Surface erosion	5,400	8,400	8,400
Total- Natural Processes	**34,800**	**55,300**	**54,500**
Human Actions			
• Channel erosion, Incision	0	0	43,250
• Landslides	0	0	900
• Surface erosion, including vineyards, grazed lands, and urban stormwater	0	0	7,500
• Roads and stream crossings	0	0	5,600
Total- Human Actions	**0**	**0**	**57,300**
TOTAL		**55,300**	**111,700**

Several methods were used to estimate the sediment load prior to European influence in the watershed, around the year 1800. Current sediment loads were estimated using modeling tools, GIS analysis, and field measurements. We estimate the amount of sediment loading that can be attributed to contemporary human activities by subtracting the year 1800 load estimates from current measurements.

---

[2] As was the case in Sonoma Creek, prior to European settlement many of the tributaries of the Napa River were historically disconnected from the mainstem.

6.2 Sediment Delivery Prior to European Settlement

Sediment sources to Sonoma Creek before Europeans settled the area-when indigenous people were the only human inhabitants-were surface erosion and natural channel processes associated with the local geology (erosion, landslides, and soil creep).

Native American land management practices included periodic burning to clear land and increase opportunities for hunting and encourage germination of fire-evolved plant species. Indigenous people also practiced planting, pruning, and coppicing (cutting vegetation to form grove-like stands). Early surveys, journals, and land grant data post-1800 indicate that upland areas of the Sonoma Valley had less dense vegetation cover than exists today, perhaps due to the cessation of native burning practices. Prior to European settlement (circa 1800), local vegetation probably consisted of a mosaic of oak woodland, redwood forest, grassland, chapparal, and riparian vegetation. The valley floor had expanses of oak savannah, oak woodland, grassland, and large areas of fresh and tidal marsh (SEC et al., 2006, Appendix A). At this time, there were no major levees, marsh draining, or ditching.

As shown in Table 5, the pre-settlement (background) load to streams from channel erosion, surface erosion, and landslides is estimated to have been 55,300 tons/year, assuming current stream channel network. Figure 3 is a map of vegetative land cover before European settlement.

Surface Erosion circa 1800

The Revised Universal Soil Loss Equation (RUSLE, see below) was used to estimate volume of sediment eroded from surface areas. Sediment loads from channel process were estimated based upon current field methods, extrapolated back to pre-settlement conditions using best professional judgment and analysis of differences of stream connectivity.

Estimating surface erosion rates requires mapping the vegetative cover during the period of interest. The Sonoma Ecology Center and Talon Associates compiled and analyzed information from all available sources, including a heritage oak census, General Land Office surveys, Father Altimira's journal, Land Grant records, historical photographs, and modern soil maps to develop a picture of the vegetative cover in the watershed, circa 1800 (see Figure 3).

To estimate erosion rates in the year 1800, researchers assigned land cover factors (C-factors) derived from the vegetation map as inputs to the RUSLE model. The land cover factor is the ratio of soil loss under specified field conditions to the corresponding loss from the standard soil plot. This factor takes into account the protection offered to the soil surface by the vegetative canopy. C-factors were determined for the different vegetation classification in Sonoma Valley using the Natural Resources Conservation Service guide. Figure 3 shows the estimated landcover of the Sonoma Creek watershed circa 1800. With this information, together with topographic and rainfall data, the model estimates a baseline (year 1800) erosion rate of 169,000 tons/year, of which 5 percent is estimated to be delivered to the stream. The baseline sediment load from surface erosion is thus estimated at 8,450 tons/year. See Table 5.

The Sonoma Ecology Center developed a GIS model that implements the Universal Soil Loss Equation (USLE), a model developed by the U.S. Department of Agriculture to predict soil erosion of soil from agricultural fields. The Revised Universal Soil Loss Equation (RUSLE), which uses the same empirical principles as USLE, includes improvements such as monthly rainfall factors. The model incorporates the major factors contributing to surface erosion in the Sonoma Valley, including vegetative cover, rainfall erosivity, and the length and slope of the eroding surface.

Channel Processes and Inputs

Sediment delivery from channel-related processes (bed and bank erosion, landslides, and creep) was determined using field methods, with extrapolations developed for unsampled areas or reaches. (We will further discuss the field methods and extrapolation techniques in the Current Sediment Sources section, below). The pre-settlement estimate of sediment loads from channel-related processes was determined by estimating the percent of measured incision, erosion, or landslide that is directly attributable to human causes. If no obvious indication of human cause (such as a road, culvert, animal grazing or in-stream structure) was found, the sediment loss was assumed to be natural background and included in the circa 1800 estimate.

6.3 Current (Year 2005) Sediment Loads

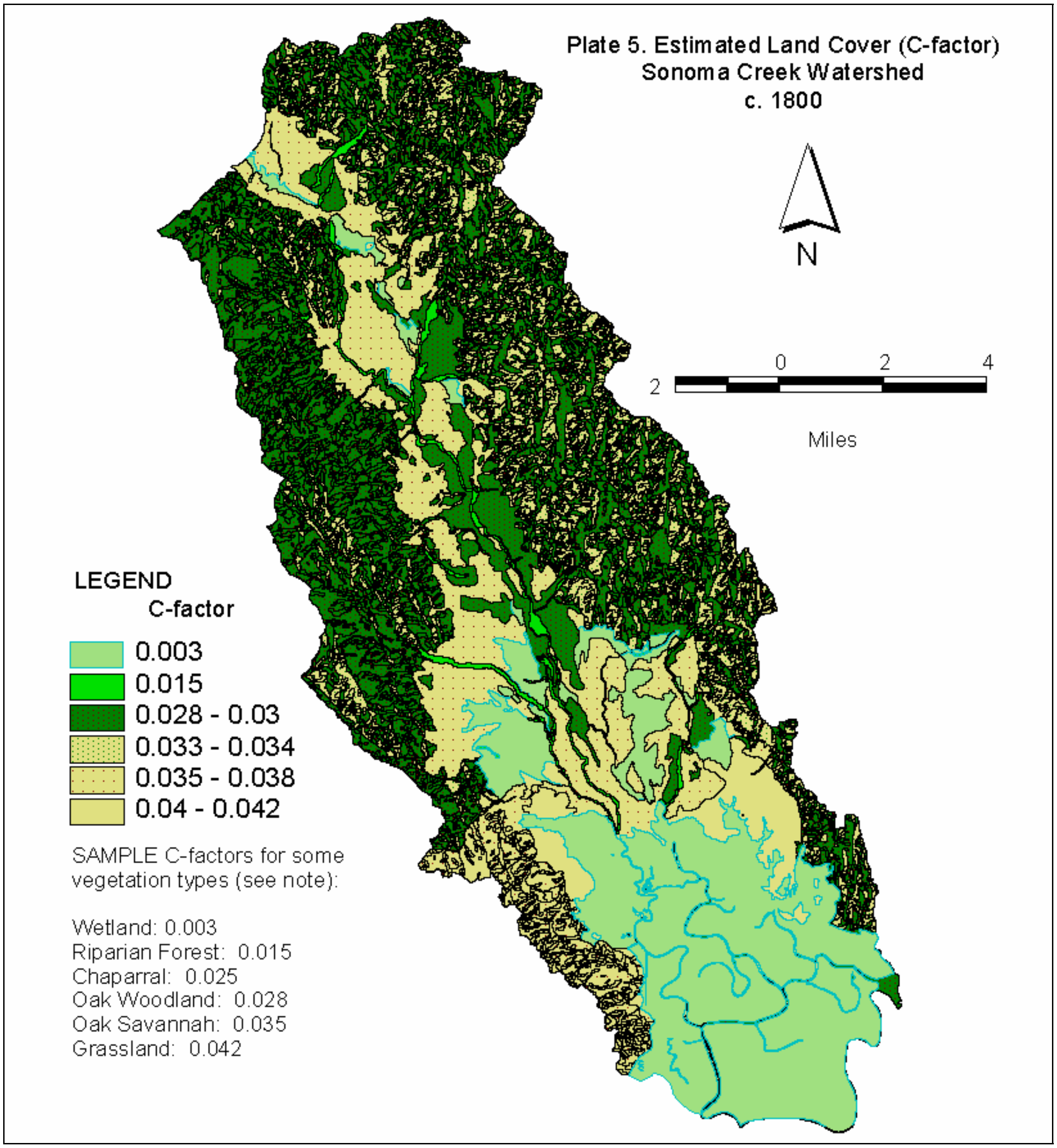
Current human-caused sources of sediment to Sonoma Creek and its tributaries include channel incision and erosion, landslides, surface erosion (including erosion from vineyards and grazed lands), roads, and stream crossings. Current sources from natural processes are those assumed to have existed in pre-settlement times (circa 1800). Table 6 breaks out historical and contemporary sediment delivery rates by source and by sub-watershed.

Water Board staff is in the process of determining sediment loads from individual source categories delivering sediment via surface erosion. These categories include vineyards, grazed lands, and urban stormwater runoff (construction stormwater, highway (CalTrans) runoff, municipal runoff, and industrial runoff).

Sediment Loads from Surface Erosion: Current Conditions

Land management practices and the amount of vegetative cover on the land significantly impact the volume of sediment that enters the creek. For example, a vineyard with full protection including cover crop will produce much less sediment than a vineyard without soil protection. Figure 4 presents current vegetative cover in the watershed.

Figure 3. Estimated Land Cover, 1800



Source: Surface Erosion Study, of the Sonoma Creek Sediment Source Analysis, Appendix A (SEC et al., 2006)

Modeling estimated surface erosion in the watershed to be 313,000 tons/year. With a sediment delivery ratio of 5 percent, the sediment load delivered to Sonoma Creek is projected to be 15,825 tons/year. The human-caused portion of the total surface erosion is calculated by subtracting the baseline (1800) surface erosion sediment delivery rate from the 2005 rate.

Methods

Sonoma Ecology Center and Talon Associates used aerial photography and interviewed local landowners to estimate soil protection and develop appropriate land cover factors for use in the RUSLE model. Depending upon the source, current sediment sources were estimated using a variety of methods, including GIS-based modeling, field methods, analysis of historical information and photographs, and extrapolation techniques. Two model scenarios were created for surface erosion: one for year 1800, and one for year 2005 (representing current conditions.) As with the year 1800, GIS analysis and RUSLE were used to estimate current sediment delivery from surface erosion. Land cover GIS data from the Sonoma Ecology Center was used to determine C-factors for the different cover types existing currently. Figure 4 shows the current land cover in the watershed.

Sediment Loads from Channel Incision, Erosion, and Landslides

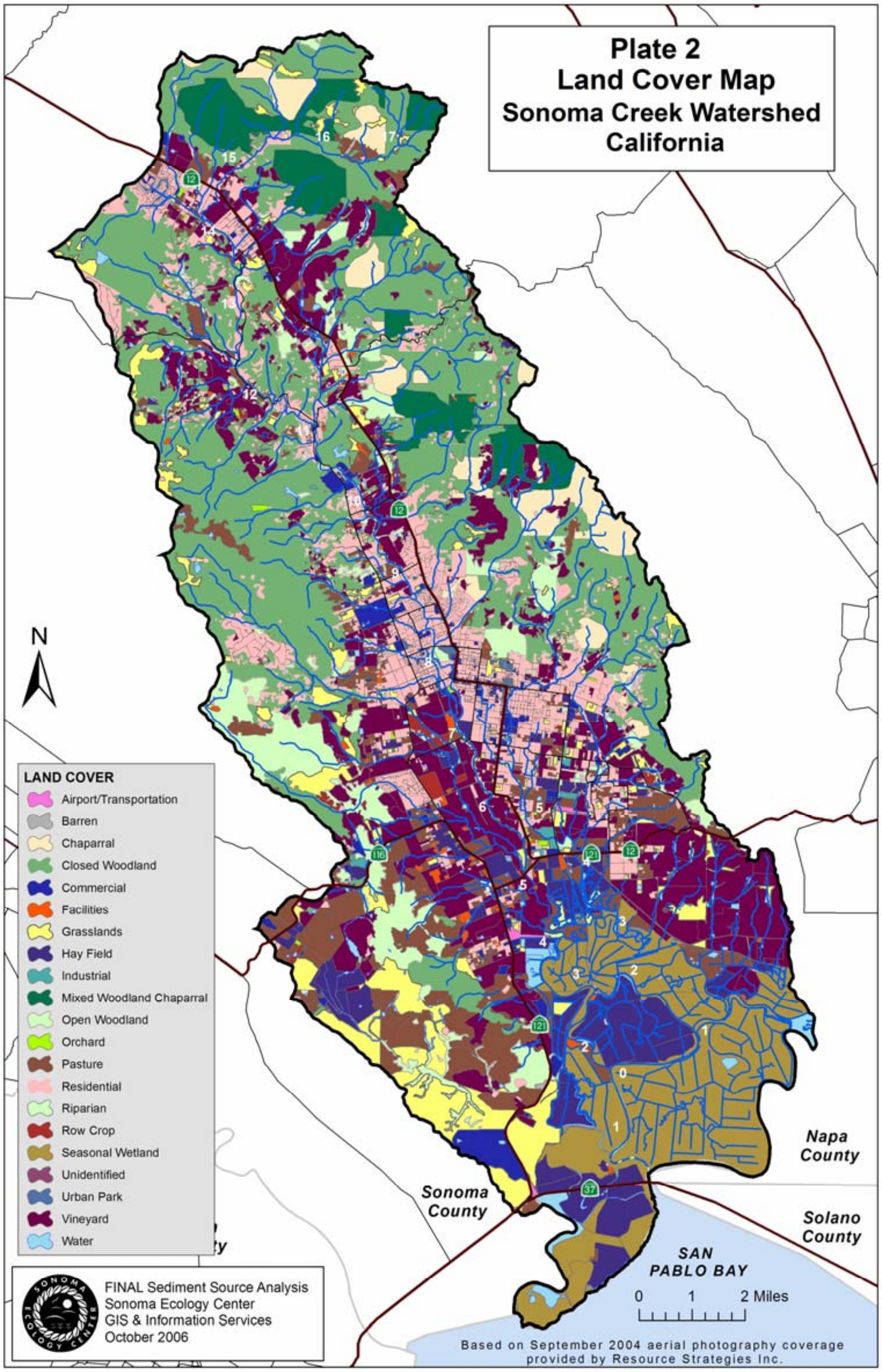
Channel-based sources discharge directly into the channel, or are generated within the channel. These sources include channel bed incision, bank erosion, and landslides and gullies within the channel corridor. Channel processes produce the majority of human-caused sediment loading to Sonoma Creek and its tributaries. Approximately 50 percent of the volume of sediment delivered from channel processes is fine sediment, which is particularly problematic for spawning habitat.

As part of the Sediment Source Analysis, Watershed Sciences (SEC et al., 2006, Appendix C) performed a geomorphic study to assess channel-based sources and rates of sedimentation. They used a combination of methods to derive sources, and the percent due to anthropogenic sources:

- Field methods
    - Continuous measurements along tributaries of sediment delivery processes including landslides, channel bed incision and bank erosion
    - Discrete measurements at 68 stations along mainstem Sonoma Creek
- Analysis of historical and current maps including as-built map and storm drainage system maps
- Analysis of aerial photography
- Mapping of geomorphic units to correlate sediment supply with morphology

These methods are further described below.

Figure 4. Current Land Cover in the Sonoma Creek Watershed



Source: Sonoma Ecology Center et al., 2006, Appendix A

Table 6. Sediment Supply by Subwatershed

Sediment Load (tons/acre)														
			1800 (Natural Background, Post- Connection)					2005					Sediment Yield (tons/acre/year)	
W'shed	Sub-watershed	Area (acres)	Channel Post-Connect	Slide Post-Connect	Soil Creep	Surface Erosion	TOTAL	Channel	Sum of Channel and Slides	Soil Creep	Sum of Road and RUSLE	TOTAL	1800 Post-Connect	2005 Current Condition
Sonoma	ADOBE E	383	0	4	11	17	33	0	4	13	77	95	0.09	0.25
Sonoma	ADOBE W	310	3	18	31	63	116	3	25	30	117	172	0.37	0.56
Sonoma	AGUA CALIENTE	2969	404	169	802	148	1523	505	683	772	401	1856	0.51	0.63
Sonoma	ASBURY	728	138	178	160	135	612	277	633	150	105	888	0.84	1.22
Sonoma	BEAR	1193	236	487	394	245	1362	262	775	377	162	1314	1.14	1.10
Sonoma	CALABAZAS	5815	736	198	1163	989	3085	1337	1570	1134	2265	4969	0.53	0.85
Sonoma	CARRIGER	4504	1462	81	856	495	2894	2658	2748	849	696	4293	0.64	0.95
Sonoma	CECILIA	160	0	0	11	10	22	6	6	12	15	33	0.14	0.21
Sonoma	DOWDALL	1978	84	36	178	178	476	336	376	169	417	962	0.24	0.49
Sonoma	EL VERANO	487	3	0	5	15	22	15	15	6	46	67	0.05	0.14
Sonoma	FELTON	1071	45	81	139	187	453	150	236	139	359	733	0.42	0.68
Sonoma	FETTERS HOT SPRGS	567	28	2	130	23	183	51	53	98	92	243	0.32	0.43
Sonoma	FISHER	1935	75	38	310	193	616	252	310	263	1118	1691	0.32	0.87
Sonoma	FOWLER	590	223	0	2	6	231	1115	1115	2	88	1205	0.39	2.04
Sonoma	FREY	1459	56	9	190	109	365	161	175	191	321	687	0.25	0.47
Sonoma	GRAHAM	1229	128	74	332	240	774	234	369	319	335	1023	0.63	0.83
Sonoma	HOLRAN	3798	2997	38	3722	266	7023	9989	10065	3725	931	14720	1.85	3.88
Sonoma	HOOD	975	83	120	215	195	613	98	224	212	185	622	0.63	0.64
Sonoma	HOOKER	3741	827	135	1309	206	2476	973	1122	1242	617	2981	0.66	0.80
Sonoma	IDEL	229	2	209	27	31	269	2	222	28	45	295	1.18	1.29
Sonoma	KENWOOD	855	9	8	60	64	141	26	34	63	346	443	0.17	0.52
Sonoma	KOHLER	388	37	7	116	35	195	62	74	99	78	250	0.50	0.65
Sonoma	LEVERONI	533	0	0	0	5	5	5	5	0	75	80	0.01	0.15

Sediment Load (tons/acre)														
			1800 (Natural Background, Post- Connection)					2005					Sediment Yield (tons/acre/year)	
W'shed	Sub-watershed	Area (acres)	Channel Post-Connect	Slide Post-Connect	Soil Creep	Surface Erosion	TOTAL	Channel	Sum of Channel and Slides	Soil Creep	Sum of Road and RUSLE	TOTAL	1800 Post-Connect	2005 Current Condition
Sonoma	LEWIS/FELDER	2152	297	11	280	118	706	495	517	223	549	1288	0.33	0.60
Sonoma	MADRONE	719	32	58	79	140	309	43	115	83	155	353	0.43	0.49
Sonoma	MILL	643	35	23	109	122	289	71	116	73	90	279	0.45	0.43
Sonoma	PEQUENO	803	43	5	169	52	269	72	80	168	325	573	0.34	0.71
Sonoma	PYTHIAN	1139	103	31	182	194	509	205	239	185	348	772	0.45	0.68
Sonoma	RODGERS	5196	473	94	675	338	1580	1351	1455	660	883	2998	0.30	0.58
Sonoma	SDC	239	4	5	29	29	66	7	12	29	12	53	0.28	0.22
Sonoma	SEARS POINT, UPPER	708	5	0	85	57	147	21	21	82	180	284	0.21	0.40
Sonoma	SEHABIGUE	60	0	0	6	13	19	1	1	6	60	67	0.32	1.12
Sonoma	SERRES	659	5	0	26	16	48	20	20	27	102	149	0.07	0.23
Sonoma	SNAG	1047	120	730	314	246	1411	241	1100	284	890	2274	1.35	2.17
Sonoma	SOBRE VISTA	1202	54	22	192	108	376	108	132	104	222	458	0.31	0.38
Sonoma	SONOMA CK (channel only from tidal to Bear Ck confluence)	294	14509	0	0	0	14509	41454	41454	n/a	n/a	41454	49.35	141.00
Sonoma	STUART	2245	320	491	516	370	1697	427	943	536	382	1861	0.76	0.83
Sonoma	SUGARLOAF	2680	265	462	724	523	1974	482	1099	660	576	2335	0.74	0.87
Sonoma	SUTTONFIELD	683	24	0	62	72	157	34	34	64	106	204	0.23	0.30
Sonoma	WARM SP E	1242	89	52	348	292	781	137	211	351	385	947	0.63	0.76
Sonoma	WARM SP W	778	44	7	156	136	342	124	132	152	350	634	0.44	0.82
Sonoma	WINKLE	923	114	42	148	175	478	175	231	146	166	543	0.52	0.59
Sonoma	YULUPA	2643	270	0	608	264	1142	449	449	545	463	1457	0.43	0.55
Sonoma	ZANE	108	1	0	21	23	44	2	2	20	145	167	0.41	1.54

Sediment Load (tons/acre)														
			1800 (Natural Background, Post- Connection)					2005					Sediment Yield (tons/acre/year)	
W'shed	Sub-watershed	Area (acres)	Channel Post-Connect	Slide Post-Connect	Soil Creep	Surface Erosion	TOTAL	Channel	Sum of Channel and Slides	Soil Creep	Sum of Road and RUSLE	TOTAL	1800 Post-Connect	2005 Current Condition
Sonoma	ZEN	1435	226	30	517	194	967	502	538	437	631	1607	0.67	1.12
Sonoma- Total		63200	24609	3953	15408	7338	51309	64937	69739	14728	15911	100378	0.81	1.59
Carneros	CARNEROS, UPPER	2021	8	2	222	111	344	162	166	222	1102	1489	0.17	0.74
Carneros	MERAZO (Renamed BOUNDARY)	281	0	0	3	13	16	0	0	0	145	145	0.06	0.52
Carneros	RAMOS	2428	25	5	146	121	297	170	180	140	995	1315	0.12	0.54
Carneros- Total		4730	34	7	371.39	245.21	657	332	345	362	2242	2949	0.14	0.62
Schell	SCHELL, UPPER	1995	36	0	2	20	58	359	359	2	90	451	0.03	0.23
Schell	ARROYO SECO	4919	275	89	836	566	1766	1377	1476	795	1304	3574	0.36	0.73
Schell	CITY WEST	999	0	0	0	20	20	10	10	0	65	75	0.02	0.08
Schell	NATHANSON	3688	354	33	664	184	1236	1180	1217	581	609	2407	0.34	0.65
Schell	HYDE	839	59	8	76	63	205	168	176	74	185	435	0.24	0.52
Schell	FRYER	993	29	0	50	20	98	288	288	60	154	502	0.10	0.51
Schell- Total		13433	753	130	1627.25	872.81	3383	3382	3526	1512	2406	7444	0.25	0.55
Grand Total		81363	**25396**	**4090**	**17407**	**8456**	**55349**	**68652**	**73610**	**16602**	**20559**	**110771**	**0.68**	**1.36**

Note: There may be slight differences in numbers (between Tables 5 and 6), due to rounding.

Channel-based Sediment Supply from Mainstem Sonoma Creek

Watershed Sciences inspected the mainstem channel at 68 stations along more than 18 miles of channel above the Highway 12 crossing. These stations were selected based on accessibility; the average distance between them was 0.25 miles. Measurements taken at each station included total incision, bed width, bankfull width, bankfull depth, floodprone width, left and right bank retreat distances, and left and right bank retreat heights. Measurements for segments between sampled reaches were interpolated from the field measurements. To calculate sediment supply along the channel, Watershed Sciences used aerial photos to assess active bank width, maximum bank width, and to interpolate active bed width over distance intervals of 200-250 ft.

Sediment supply due to incision was calculated for each distance interval as the product of incision depth, active bed width, and distance interval. The sediment supply from all the intervals was summed together to estimate the total supply over the 18-mile mainstem survey area (SEC et al., 2006, Appendix C). The total sediment supply from mainstem Sonoma Creek is 41,500 tons/year.

Channel-based Sediment Supply from Tributaries

One of the first steps to estimating sediment supply from tributaries was to develop a comprehensive stream channel map. Watershed Sciences used existing GIS maps provided by the Sonoma Ecology Center as the base map, and additional channels were added based on analysis of aerial photographs. Documented storm drains and ditches and culverts observed in the field were also added to the stream map. Aerial photographs were also used to estimate landslides.

Continuous measurements were taken along tributaries by walking along the channels and measuring the amount of channel bed incision, bank erosion, landsliding, gullying, or dry raveling (sediment sloughing off in dry conditions) occurring within the channel corridor. To estimate the time period over which the sediment loss occurred, they considered multiple factors, including the freshness of bank escarpments, age of trees or other vegetation within erosional features, and the depth of incision below structures such as retaining walls or bridge abutments. The amount of sediment supplied to a reach was normalized to calculate sediment supply per unit length, in order to allow comparisons between channels. The percent of erosion caused by human activity was estimated in the field based on whether there were obvious signs of human actions, such as culverts or roads. The percent of fine sediment from erosional features was estimated visually.

In order to test whether sediment supply could be correlated with geomorphic attributes such as landform unit and the length of the upstream drainage network, Watershed Sciences mapped geomorphic units using both USGS topographic maps and geologic maps. For each geomorphic unit, sediment supply (expressed as cubic feet per foot of channel) was plotted against upstream drainage length. Figure 5 shows this plot. To evaluate the correlation between sediment supply and drainage for each geomorphic unit, the R-squared values were analyzed. With R-square values between 0.5 and 0.97, the correlations were reasonably good and allowed sediment delivery from unsampled reaches to be extrapolated. Not surprisingly, the analysis shows that geology plays a large role in determining sediment supply.

The total sediment supply from tributaries is shown in Tables 5 and 6.

Roads and Stream Crossings

Upland field surveys conducted in fall 2005 (SEC et al., 2006, Appendix B) measured sediment input to stream channels from road-related sources, making observations at 43 sites throughout the watershed. Trso (SEC et al., 2006, Appendix B) estimated that 50 percent of sediment delivered to streams from roads is coarse sediment (2-11.2 mm gravel), and the other 50 percent is fines (sand, silt, or clay). According to field surveys, about 50 percent of the road segments near the stream-road crossings had inboard ditches, and 100 percent delivery to the stream of the road cutslope sediment over distances of 25-60 meters.

Observed erosion at road cutslopes was low due to vegetation cover: 80 percent of the road-stream crossings showed negligible or no fluvial (river-related) erosion. Vineyard roads also exhibited mostly non-erosive conditions due to cover such as straw mulch or a grassed road surface. Unpaved (dirt) roads, mostly located in state and regional parks, also exhibited non-erosive conditions.

Trso's modeling (see below) estimated sediment delivery from roads (due to road tread erosion and cutslope erosion) in the watershed to be 5,250 tons/year, or approximately 5 tons per mile of road. The typical rates of sediment delivery across the 61 sub-watersheds he modeled range from 0.01-0.09 tons/acre/year. Modeling predicts significantly higher rates, ranging from 0.10-0.19 tons/acre/year, in the following sub-watersheds:

- Adobe Canyon West
- Felton
- Fisher
- Fryer
- Kenwood
- Lewis/Felder
- Pythian
- Schell North
- Skaggs North

- Third Napa North

The model predicts that roads in the Kenwood area have relatively high erosion rates. The highest sediment delivery segments are located near the top of the tributary watershed alluvial fans, likely due to higher road cut heights and unpaved road surfaces.

Methods

Trso used road data (from both existing GIS information and field surveys conducted as part of the sediment source analysis) to group roads into categories: 1) vineyard roads, 2) dirt roads, 3) presumed direct roads, and 4) paved roads. He categorized the percentage of eroded sediment that is actually delivered to the watercourse ("delivery ratio") by the distance of the road to a watercourse, as follows:

- Road segments directly delivering sediment deliver 100 percent of eroded sediment to streams.
- Road segments within 100 feet of a stream deliver 35 percent of eroded sediment to the stream.
- Road segments within 100-200 feet of a stream deliver 10 percent of eroded sediment to the stream.
- Road segments further than 200 feet from a stream are assumed to contribute no sediment to the stream.

Trso estimated road surface erosion and delivery using SEDMODL2, a GIS-based model developed by Boise Cascade to identify road segments that deliver sediment to streams from road treads and road cuts, and the relative amount of sediment delivered. The model developed to estimate sediment delivery from roads in the Sonoma Creek watershed incorporated the following information, which was entered into GIS layers:

- 10-meter digital elevation model
- Land use
- Simplified geology, with geologic material stratified into five units based on potential for erosion
- Road network
- Stream channel network
- Data from field surveys and aerial photographs

The model calculates the total sediment delivery from each road segment as the sum of road tread and cutslope erosion. The calculation is based on road erosion factors as shown below:

Road Tread Erosion (tons/yr) = *Geologic Erosion Rate*Tread Surfacing Factor*Traffic Factor*Segment Length*Road Width*Road Slope Factor*Precipitation Factor*Delivery Factor*

Road Cutslope Erosion (tons/yr) = *Geologic Erosion Rate*Cutslope Cover Factor*Segment Length*Cutslope Height*Delivery Factor*

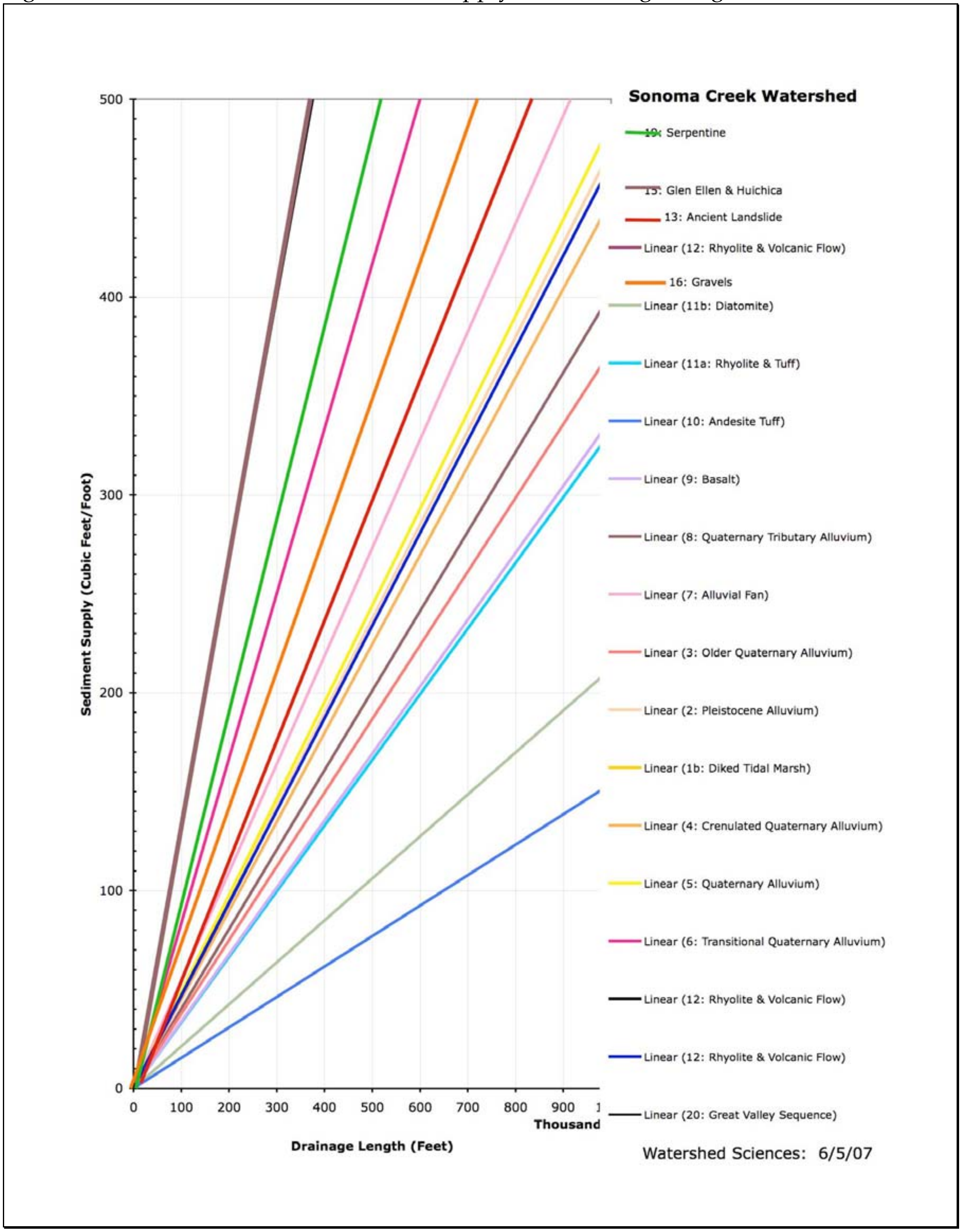
The SEDMODL estimates are calculated based in part on the location of the roads in relation to streams. The road and stream network used was based on the best available data, supplemented and validated by field observations; however it is possible that some roads or smaller, headwater channels were not captured. Actual sediment delivery from roads may be higher than currently estimated.

Water Board staff are in the process of evaluating methods to refine the estimate of sediment contributed by road-related erosion. One possible approach is to estimate the percentage of streams not depicted, and use a factor to account for the additional sediment delivery.

Stream Crossings

Trso assumed that 100 percent of sediment produced from fluvial (river-related) erosion at stream-road crossings is delivered to the stream. Road and stream channel network data developed for the model indicates that there are 1,677 stream crossings in the watershed. From field observations, Trso estimated that most of the observed fluvial erosion at crossings has occurred in the last 10 years. From his field observations he estimates an average erosion rate at stream-road crossings of 0.2 tons per road crossing per year. Therefore, he estimates that stream crossings contribute 336 tons of sediment to stream channels annually (SEC et al., 2006, Appendix B).

Figure 5: Correlation between Sediment Supply and Drainage Length



Source: Excerpt from Appendix C of Sediment Source Analysis, Technical Memo on Sediment Source Analysis in Sonoma Creek (SEC et al., 2006, Appendix C)

7. TMDL, Linkage Analysis and Allocations

7.1 Introduction

The total maximum daily load (TMDL) is the *total* sediment load that can be discharged into Sonoma Creek and its tributaries without violating water quality standards. When the TMDL is achieved, the impairment due to sediment will be eliminated. As part of the scientific justification for the Basin Plan amendment, each TMDL Staff Report includes a "linkage analysis" that explains Water Board staff's reasoning in arriving at its TMDL strategy. The linkage analysis conveys our understanding of the relationships between the pollutant of concern, current habitat conditions, and our determination that the TMDL will resolve the problem.

In this section, we evaluate linkages between sediment inputs and impacts of those sediment contributions on habitat conditions and establish sediment load allocations each source category must meet in order to achieve the TMDL.

7.2 Approach to Development of the Linkage Analysis

Most total maximum daily loads for sediment in natural stream channels are expressed in terms of mass per unit area per unit time. We propose an alternative approach of expressing the TMDL as a percentage of the natural background rate of sediment input to channels. We have taken this approach because:

- The Sonoma Creek watershed has a Mediterranean climate and active tectonic setting. Therefore, natural sediment loads are highly variable and native stream biota are adapted to large infrequent sediment pulses associated with natural disturbances (e.g., large storm events, wildfires, and major earthquakes).
- Native stream biota are not adapted, however, to the chronic increases in fine sediment load caused by human land use activities that disturb vegetation cover and/or infiltration capacity of soil (e.g., road-related erosion, agriculture, construction, timber harvest, livestock grazing, etc.). Under a natural sediment input regime, fine sediment input would be very low in most years, and the amount of fine sediment stored in the channel following a large disturbance would return relatively rapidly to levels favorable for fish spawning and rearing.

In order to emulate natural sediment dynamics and allow adaptations of native biota to infrequent pulse disturbances (but not to chronic human-caused disturbances), we propose to express the TMDL as a percentage of natural input rate to channels.

7.3 Establishing the TMDL

Linking channel conditions to sediment supply is challenging because channel form and sediment deposits depend upon the processes of sediment supply into and transport through stream channels, both of which vary depending on time and location. In addition to sediment supply, channel transport capacity and storage are influenced by: a) magnitude, duration, and frequency of high flows; b) channel slope and depth; and c) channel roughness, or the presence of features that concentrate or disperse flow energy. For these reasons, time lags between sediment input and discharge may be several years or decades, and specific changes in the channel due to changes in sediment supply may vary substantially from one reach to another. These challenges acknowledged, the following approaches to linking sediment inputs and channel attributes have been pursued for developing natural stream channel sediment TMDLs:

- Selecting for comparison a "reference" watershed or time period, where all water quality objectives are met and salmonid populations are robust
- Comparing sediment supply to channel attributes related to sediment supply, i.e. comparing sediment supply to gravel permeability
- Comparing current values for channel attributes related to sediment supply to numeric targets.

In order to determine what percentage above natural background sediment load will be needed to attain sediment-related water quality standards, we reviewed previously adopted sediment TMDLs for stream channels in the California Coast Range, and found two sediment TMDLs that have been adopted where the TMDL is expressed as a percentage of natural background load. The North Coast Water Board developed these TMDLs based on comparison to either a reference watershed or reference time-period where water quality standards are/were attained:

- The sediment TMDL for Redwood Creek in Humboldt County (Region 1) used a reference watershed. The TMDL is set at 117 percent of natural background sediment load.
- The sediment TMDL for the Noyo River on the Mendocino Coast used a reference time period. The TMDL is set at 125 percent of natural background.

In both cases, a reference state was identified where salmonid populations are/were robust, and inferentially, where water quality objectives for sediment-related parameters are/were attained. Similar to the Sonoma Creek TMDL, the primary goal of these TMDLs is the recovery of native salmonid populations.

Of the two watersheds, Noyo shares more common attributes with Sonoma Creek, including a similar uplift rate, similar average annual rainfall, common occurrence of weak sedimentary rocks that are susceptible to substantial increases in sediment supply in response to land use disturbances, and predominance of channel incision and erosion, and gullies as significant human-caused sediment sources. Therefore, Noyo River under historical conditions—circa 1940s—when there was a modest increase in sediment load (e.g., 125 percent of natural background) and robust steelhead and salmon runs—appears to be a suitable reference watershed for evaluating Sonoma Creek's assimilative capacity for sediment.

Therefore, we find that a sediment load of 125 percent of natural background to Sonoma Creek, together with restoration of desired habitat conditions, should be supportive of a healthy steelhead population and result in attainment of the numeric target/desired condition. A TMDL of 125 percent of natural background would also assure attainment of the water quality objective for turbidity because the required reduction in sediment loads will lower fine sediment input, thereby lowering suspended sediment and turbidity. The large reductions in sediment input (particularly fine sediment) called for by the TMDL should reduce turbidity from current conditions (where it is unclear whether there is a violation of the turbidity objective), to levels where we can be confident that beneficial uses are protected.

To provide additional assurance that a TMDL of 125 percent of natural background will result in attainment of the numeric target, staff are evaluating methods to correlate sediment input (scaled for stream power[3]) with gravel permeability. Such a correlation was done for the Napa River TMDL, and it is very likely the same correlation can be applied to the Sonoma Creek watershed.

7.4 Allocations

Consistent with the approach used in other northwestern California streams, the Sonoma Creek sediment TMDL is established as 125 percent of the natural background , which equals 69,000 tons of sediment per year. Allocations by sediment source categories are also specified as a percentage of the natural background. Allocations expressed in terms of estimated percent reductions are consistent with the approved sediment TMDL for Deep Creek, Montana as cited in the *Protocol for Developing Sediment TMDLs* (USEPA, 1999).

Table 7 summarizes these allocations, including estimates of the percent reduction from each source's current contribution to the total load. Overall, discharges from human-caused sources of sediment must be reduced from current (2005) levels by approximately 75 percent, in order to achieve the TMDL of 125 percent of natural background.

[3] Stream power is the energy available to transport sediment, and is a function of water flow rate and energy slope (approximated by channel slope).

Table 7. Sediment Load Allocation in the Sonoma Creek Watershed (tons/year)

	Recent year (2005) condition	Allocation		Percent reduction
		tons/year	Percent Natural Background	
Natural Processes				
• Channel Erosion, Incision	25,400	25,400	47	0
• Landslides	4,100	4,100	8	0
• Soil Creep	16,600	16,600	30	0
• Surface Erosion	8,400	8,400	15	0
Total- Natural Processes	54,500	54,500	100	0
Human Actions				
• Channel Erosion, Incision	43,250	8,000	12	82
• Landslides	900	450	1	50
• Surface Erosion, including Vineyards, Grazed Lands, and Urban Stormwater	7,500	3,000	6	60
• Roads and stream crossings	5,600	3,000	6	46
Total-Human Actions	57,300	14,500	25	75
TOTAL	111,700	69,000	125	
TMDL = 125% Natural Background = 69,000 tons/year				
Note: Natural Background = 55,000 tons/year (Sediment loading during Pre-European settlement period)				

Compliance with the TMDL will be evaluated at Sonoma Creek at the Schellville-HWY 121 bridge. This station approximates the downstream limit of freshwater Sonoma Creek salmonid habitat. Attainment of the TMDL equates to a sediment load in Sonoma Creek at Schellville bridge of approximately 207 metric tons per km^2 per year.

7.5 Margin of Safety

The Clean Water Act, Section 303(d) and associated regulations at 40 CFR § 130.7 require that a TMDL includes a margin of safety that accounts for any lack of knowledge about the relationship between the pollutant loads and desired receiving water quality. The margin of safety may be employed implicitly by making conservative assumptions (USEPA, 1991). For the Sonoma Creek sediment TMDL, we employed conservative assumptions in setting targets for parameters that are primarily (gravel permeability) and secondarily (pool depth and frequency) related to sedimentation.

We find that setting the "increasing trend" target for pool depth and frequency will yield significant benefits above and beyond those needed to address primary sediment-related water quality objectives. Specifically, attainment of the target for pool depth and frequency will require both sediment source reductions and channel restoration actions that will enhance the quantity and quality of spawning and rearing habitat in Sonoma Creek. As such, the pool depth and frequency target provides additional benefits to salmonids above those required solely to achieve sediment-related water quality standards.

Similarly, an implicit margin of safety for sediment-related water quality standards is also provided through implementation actions designed to address other key stressors of salmon and steelhead populations in the Sonoma Creek watershed, including actions to protect and/or enhance baseflow, fish passage, and habitat complexity, as described in the implementation plan (Chapter 8).

7.6 Seasonal Variation and Critical Conditions

The TMDL must describe how seasonal variations were considered. Sediment input to channels in the Sonoma Creek watershed and its effects on beneficial uses inherently vary on seasonal, annual, and longer timeframes. The TMDL and allocations are designed to apply to the sources, and are expressed as a percentage of the natural load.

In the California Coast Range, almost all sediment delivery to channels occurs during the wet season. Although rainfall patterns vary on seasonal, inter-annual, and longer timeframes, most precipitation occurs between the months of October and April. Sediment input to channels from natural processes is positively correlated to precipitation volume and/or intensity. Shallow landslide failures, whether caused by natural processes or land use activities, typically occur during high intensity rain events occurring when the soil is already saturated by previous storms.

Most channel incision and associated bank erosion occurs during large infrequent runoff events (e.g., recurrence intervals greater than 10 years, or "10-year storms" or greater), and/or in years of average or above normal runoff that immediately follow such events. Other land-use related sources, such as sheetwash erosion associated with vineyards and/or roads, are chronic, occurring during the wet season almost every year, with erosion rates being proportional to precipitation.

Critical conditions with regard to flow are addressed through implementation actions designed to protect or enhance baseflow as described in Chapter 8. Other critical water quality parameters are also addressed including the target for pool depth and frequency that addresses sediment-related water quality objectives and water quality objectives for habitat complexity (e.g., as an aspect of population and community ecology). Implementation actions are also recognized to protect and/or enhance fish passage and baseflow.

8. Implementation Plan

8.1 Introduction

A TMDL implementation plan is a detailed description of actions stakeholders need to take to achieve the TMDL, support beneficial uses, and restore a sustainable fishery.

The goals of the Sonoma Creek Sediment TMDL and Habitat Enhancement Plan are to:

- Conserve the steelhead trout population
- Enhance the overall health of the native fish community
- Protect and enhance habitat for native aquatic species
- Enhance the aesthetic and recreational values of the river and its tributaries

To achieve these goals, stakeholders in the watershed must work to:

- Reduce sediment loads, and fine sediment in particular, to Sonoma Creek and its tributaries
- Attain and maintain suitable gravel quality in freshwater reaches of Sonoma Creek and its tributaries
- Reduce and prevent channel incision
- Repair large sources of sediment supply (i.e. landslides)
- Enhance channel complexity (i.e., by adding and encouraging retention of large woody debris)

In this section we describe actions recommended to reduce sediment supply and enhance stream habitat, as needed to achieve the above stated goals. In addition to actions needed to resolve sediment, we conclude that progress is also needed toward resolution of other factors limiting steelhead productivity and survival in the Sonoma Creek watershed. Therefore, we recommend additional management actions to address other significant factors limiting steelhead, as part of a broader habitat enhancement plan discussed at the end of this chapter.

8.2 Key Considerations Regarding Implementation

Total sediment delivery to channels associated with human and land use activities needs to be reduced by approximately 75 percent from current values in order to meet the proposed targets and allocations for sediment and achieve the TMDL. The best solutions to sediment supply and habitat quality issues in this watershed are those “owned” by stakeholders. Therefore, we support collaborative stewardship efforts that select and implement the most effective and appropriate best management practices described later on in this section. Specifically, we support cost-effective sediment source reduction by sediment source-control "cooperatives" that could be administered by local public agencies or other capable and interested groups.

Implementation measures and efforts should build upon existing programs, such as those led by Sonoma County, the Southern Sonoma Resource Conservation District (RCD), and the Sonoma Ecology Center. These entities currently work on programs geared towards assisting landowners put into use effective erosion control and good stewardship best management practices.

8.3 Legal Authorities and Requirements

The Water Board's legal authorities to require dischargers of sediment to implement water pollution control actions are derived from the federal Clean Water Act and California's Porter-Cologne Water Quality Control Act.. As explained above, the Clean Water Act requires states to list polluted waterbodies and address impairments through TMDLs. Porter Cologne gives Water Boards authority to issue discharge prohibitions, waste discharge requirements, (WDRs), and/or waiver conditions, in order to control actual and potential discharges of pollutants from point and nonpoint sources into waters of the state (California Water Code section 13000 et seq.). California also regulates and controls nonpoint source pollution as specified in the *Plan for California's Nonpoint Source Pollution Control Program* (State Board and California Coastal Commission, 2000) and the Policy for Implementation and Enforcement of California's Nonpoint Source Pollution Control Program (State Board, 2004). These policies require all current and future nonpoint sources to be regulated under waste discharge requirements or waivers, and/or waste discharge prohibitions (California Water Code 13369). Under these policies, waivers of waste discharge requirements must be conditioned on a monitoring program to ensure that water quality is protected.

8.4 Implementation Strategy

To achieve our goals, the Sonoma Creek Sediment TMDL and Habitat Enhancement Plan will include implementation measures both to control sediment and to restore stream complexity and habitat. In addition to regulatory controls on land uses that add sediment to Sonoma Creek, our strategy also includes collaborative, multi-stakeholder actions to address habitat issues such as lack of in-stream shelter and large woody debris, channel incision, and low summer baseflows. The plan to address sediment sources will build upon local, existing efforts such as landowner-assistance programs led by Sonoma Ecology Center, the Southern Sonoma RCD, and UC Cooperative Extension. Likewise, the habitat enhancement plan will rely in large part on local, collaborative restoration projects and programs.

8.5 Sediment Reduction and Control/New Regulatory Programs

The sediment control plan includes recommended actions for each major source category (channel incision, roads, grazing, vineyards, and urban stormwater). For each source category, we summarize relevant existing plans, policies, or regulations, and discuss approaches to further reduce sediment loads through new regulatory programs, or through expansion and improvement of existing programs.

As discussed above, state policies require all current and future nonpoint sources to be regulated under waste discharge requirements or waivers, and/or waste discharge prohibitions. Significant sediment sources that are not currently regulated will be regulated by new regulatory programs. We expect new regulatory programs to address sediment discharges from roads, vineyards, and grazing lands. In addition, we anticipate existing programs will be expanded to address hydromodification and further reduce sediment.

Channel Incision

There are a number of ways to address channel incision. Maintaining intact riparian corridors (via setback requirements, if necessary) accelerates natural recovery. Reach-based channel restoration projects can restore habitat locally and help with downstream recovery as well. To address channel incision in Sonoma Creek and its tributaries, we will rely on multiple approaches, including regulatory programs to prevent increases in stream peak flow and avoid direct impacts to the stream corridor, and collaborative stream restoration and habitat enhancement projects (see the Habitat Enhancement Plan section of this report).

Sediment produced by channel incision will be the TMDL's highest priority for source reduction and control because this sediment is produced adjacent to the streambed, and is likely to have a greater effect on fine sediment deposition at spawning and rearing sites in Sonoma Creek than more remote sources of sediment delivery. In addition to being a significant sediment source, channel incision devastates the physical habitat structure of the creek by disconnecting the creek from its floodplain, destabilizing streambanks and riparian vegetation, and eliminating pools, riffles, and in-stream shelter. Channel incision problems along Sonoma Creek and its tributaries result from multiple historic and ongoing disturbances, some of which are local and/or direct, and others that are indirect and farther away.

Roads and Stream Crossings

Sonoma County does not currently have written policies on road construction and maintenance or stream crossings (UC Berkeley Extension, 2001). The FishNet 4C guidelines, which are already being implemented in San Mateo and Santa Cruz

Counties, could form the basis for future County or Water Board regulatory programs regarding roads.

According to GIS data developed by Sonoma County and the Sonoma Ecology Center, there are 1,565 km (972 miles) of roads in the watershed, of which 454 miles are known or presumed to be unpaved (SEC et al., 2006, Appendix B). In addition there are an estimated 1,677 stream crossings in the watershed. (See section 6, Sources.)

Erosion of unpaved roads, which can continue to erode as long as they are in use, can supply large amounts of sediment to streams. Roads can also concentrate and direct runoff onto un-vegetated areas, causing additional erosion. On the other hand, road designs that disperse runoff are less likely to cause erosion or create landslides. Similarly, culverts that are adequately sized and appropriately placed are less likely to concentrate flow and cause blow-outs, or plug or destabilize the stream.

FishNet 4C , a coalition of six central California coastal counties (Mendocino, Sonoma, Marin, San Mateo, Santa Cruz, and Monterey) formed in response to Endangered Species Act listings of coho and steelhead in central California, has developed *Guidelines for Protecting Aquatic Habitat and Salmon Fisheries for County Road Maintenance* (FishNet4C et al., 2004*)*. These guidelines address selection, design, and maintenance of best management practices for roads and stream crossings.

Vineyards

Vineyards, particularly those located on hillsides with highly erodible soils, can be significant sources of sediment to streams. Erosion and sediment control can be accomplished by measures such as soil protection (i.e., cover cropping, mulching, or revegetation); and stormwater management (i.e.,with drainage swales, vegetative filter strips, and sediment basins. The Southern Sonoma RCD has developed *The Vineyard Manual* to educate growers on vineyard best management practices, including erosion control. In addition, the RCD provides technical assistance and in-field consultations to landowners regarding erosion and sediment control practices.

New vineyard plantings and replantings are regulated by Sonoma County via the Sonoma County Vineyard Erosion and Sediment Control Ordinance, administered by the County Agricultural Commissioner. This ordinance prohibits new vineyard plantings on land steeper than 50 percent slope. It further categorizes plantings by "level."

- Level I plantings (on lands with highly erodible soils with slopes less than 10 percent, or lands with less erodible soils with slopes less than 15 percent) require notification to the County Agricultural Commissioner.
- Level II vineyard plantings, on highly erodible soils with slopes between 10 percent and 15 percent, or on land with less erodible soils with slopes between 15 percent and 30 percent, require erosion and sediment control plans. These

erosion and sediment control plan must be reviewed and certified by a county-recognized civil engineer, or prepared by such an engineer.

- Level III plantings, on lands with highly erodible soils with slopes of 15 percent to 50 percent, or land with less erodible soils with slope of 30 percent to 50 percent, must be prepared by a qualified civil engineer or professional, and be reviewed and certified by a county-recognized civil engineer.

Another important requirement of the ordinance is the stream setback requirement: 25-ft. setback for Level 1, and 50-ft. setback for Levels II and III. Setbacks not only decrease sediment loads from erosion, but also aid natural stream recovery and may slow or decrease channel incision.

Each County-required erosion and sediment control plan must describe all best management practices to be used to protect disturbed areas, manage stormwater runoff, and minimize the discharge of sediment from the vineyard site (Sonoma County, 2001). The levels and requirements for vineyard replantings are similar to those for new plantings, except that the allowable slopes are slightly steeper.

Existing vineyards not undergoing replanting are not currently regulated. Additional measures that may achieve needed sediment reductions include expanding or creating regulatory programs to address existing vineyards, and incorporating performance measures such as controlling runoff so as not to increase peak flows in streams.

While regulatory programs will be needed to control sediment, effective implementation of best management practices may depend on providing incentives and technical assistance to landowners. Third-party certification programs, such as the Fish Friendly Farming program, can provide incentive-based, collaborative methods for complying with state and federal water quality laws, including those related to sediment. Farmers who participate in the program complete a Farm Conservation Plan that addresses water quality and environmental issues holistically. The Fish Friendly Farming program has been very successful in the Napa Valley, with about 6,000 acres of vineyards covered under the program. We support expansion of this program into Sonoma Valley.

Many growers interviewed as part of the Interview Report on Best Management Practices in Sonoma Valley (Sonoma Valley Vintners & Growers Alliance, 2005) stated that the cost of erosion control was “recouped by not having to spend money fixing erosion problems.” In addition, growers stated that they received assistance from the RCD or Agricultural Commissioner in designing and implementing an erosion control strategy. Many vineyards already have best management practices in place, and we expect that those that are already effectively controlling erosion and sedimentation will only be required to document their good practices in order to be in compliance with the TMDL.

Livestock Grazing

The Water Board is currently developing waiver conditions for waste discharge requirements on grazing lands. In addition to sediment, grazing lands are also sources of nutrients and pathogens, pollutants for which Sonoma Creek is also listed as impaired.

The State Water Board and the California Coastal Commission (2004) have identified management measures to address nonpoint source pollution from grazing activities. In response to nonpoint source pollution concerns, livestock industry representatives and members of the public formed the Range Management Advisory Committee . The Committee developed a California Rangeland Water Quality Management Plan, which recommends that ranchers complete rangeland Water Quality Management Plans for their respective ranches.

Grazing livestock can cause "sheetwash erosion," which is characterized by less concentrated flows than gully erosion, but nevertheless can move a significant volume of soil downslope in a rainstorm. An effective means of reducing sheetwash erosion from livestock grazing could involve adopting livestock and/or range management practices that result in sufficient plant material being left on the ground to effectively resist sheetwash erosion. One such approach of this type, that has been successfully applied to control soil erosion at many California rangeland sites, is a residual dry matter standard or target, with residual dry matter being defined as "the old plant material left standing or on the ground at the beginning of a new growing season" (University of California, 2002). Other measures that could control sediment, as well as reduce sediment loads from gullies and landslides, include: modification of grazing strategies and locations, exclusion fencing that keeps livestock out of creeks and away from creek banks, planting of native woody vegetation, diversion or dispersion of concentrated runoff from roads, and construction of alternative water supplies for livestock.

The University of California Cooperative Extension (UCCE) and the RCD are currently engaged in a number of programs focused on grazing management practices. Water Board staff are interested in working collaboratively with these and other interested groups to develop appropriate performance measures (such as a target for the percentage of residual dry matter target), as well as incentive programs to accelerate natural recovery of gullies and landslides. Incentives for proactive participation by ranchers could involve grant funding for rangeland and sediment source inventories and implementation actions, or waivers of waste discharge requirements.

Urban Stormwater Runoff

Sediment sources related to urban stormwater runoff in the Sonoma Creek watershed include construction sites, industrial sites, municipal Stormwater conveyance systems, and state highways. These sources are regulated by National Pollutant Discharge

Elimination System (NPDES) permits, which require control of sediment discharges. Details of the state and regional Water Boards' programs to regulate urban stormwater runoff can be found at http://www.swrcb.ca.gov/stormwtr/index.html.

The Sonoma Creek sediment TMDL will propose no new regulatory requirements for these sources. Wasteload allocations for sediment will be implemented and achieved via erosion and sedimentation controls (BMPs) required in existing permits. The erosion and sedimentation control (BMPs) requirements constitute water quality based effluent limitations. Continued compliance with these existing permits is expected to achieve allocations. The following is a general overview of these existing programs.

Construction Stormwater Program

Property owners or developers whose projects disturb one or more acres of soil, or whose projects disturb less than one acre but are part of a larger common plan of development that in total disturbs 1 or more acres, are required to obtain coverage under the *General Permit for Discharges of Storm Water Associated with Construction Activity* (Construction General Permit, 99-08-DWQ). Construction activity subject to this permit includes clearing, grading and disturbances to the ground such as stockpiling and excavation. It does not include regular maintenance activities performed to restore the original line, grade, or capacity of a facility.

The Construction General Permit requires development and implementation of a Storm Water Pollution Prevention Plan (SWPPP). The SWPPP should contain a site map(s) showing the construction site perimeter, existing and proposed buildings, lots, roadways, storm water collection and discharge points, general topography both before and after construction, and drainage patterns across the project. The SWPPP must also list best management practices (BMPs) that the discharger will use to minimize storm water runoff, and the placement of those BMPs. Additionally, the SWPPP must contain a visual monitoring program; a chemical monitoring program for "non-visible" pollutants to be implemented if there is a failure of BMPs; and a sediment monitoring plan if the site discharges directly to a waterbody listed on the 303(d) list as impaired by sediment. Section A of the Construction General Permit describes the elements that must be contained in a SWPPP.

Industrial Stormwater Program

Facilities in the Sonoma Creek watershed that are permitted under the *Industrial Stormwater General Permit* include properties involved in wine production.

The General Industrial Permit (order 97-03-DWQ) is an NPDES permit that regulates discharges associated with 10 broad categories of industrial activities. It requires implementation of management measures that will achieve the performance standard of "best available technology economically achievable" (BAT) and the "best conventional pollutant control technology," and development of a Storm Water Pollution Prevention Plan (SWPPP) and a monitoring plan. The SWPPP must identify sources of pollutants as well as the means to manage them to reduce stormwater pollution, including sediment pollution. An annual report is required each July 1.

The facility operator must submit an NOI for each industrial facility that is required by U.S. Environmental Protection Agency (U.S.EPA) regulations to obtain a storm water permit. The required industrial facilities are listed in Attachment 1 of the General Permit and are also listed in 40 Code of Federal Regulations Section 122.26(b)(14). The facility operator is typically the owner of the business or operation where the industrial activities requiring a storm water permit occur. The facility operator is responsible for all permit related activities at the facility.

Municipal Stormwater Program

The *Municipal Storm Water Permitting Program* regulates storm water discharges from municipal separate storm sewer systems (MS4s). MS4 permits were issued in two phases:

- Under Phase I, which started in 1990, the Regional Water Quality Control Boards have adopted National Pollutant Discharge Elimination System General Permit (NPDES) storm water permits for medium (serving between 100,000 and 250,000 people) and large (serving 250,000 people) municipalities. Most of these permits are issued to a group of co-permittees encompassing an entire metropolitan area. These permits are reissued as the permits expire.
- As part of Phase II, the program in which agencies and facilities in Sonoma County falls under, the State Water Resources Control Board adopted a General Permit for the Discharge of Storm Water from Small MS4s (WQ Order No. 2003-0005-DWQ) to provide permit coverage for smaller municipalities, including non-traditional Small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

The MS4 permits require the discharger to develop and implement a Storm Water Management Plan/Program with the goal of reducing the discharge of pollutants to the maximum extent practicable (MEP, the performance standard specified in Section 402(p) of the Clean Water Act). Management plans or programs specify the best management practices that will be used to address particular program areas, including public education and outreach; illicit discharge detection and elimination; construction and post-construction site management; and good housekeeping practices for municipal operations.

State Highways Stormwater Program
The California Department of transportation (Caltrans) is responsible for runoff from state highways and associated construction activities. Discharges from state highways are regulated via a *Statewide Stormwater Permit* issued to Caltrans.

8.6 Habitat Enhancement Plan

In Sonoma Creek, as well as in many Bay Area watersheds, controlling sediment will not be enough to restore and protect the steelhead fishery. In addition to reducing sediment supply, specific actions are also needed to:

- Prevent and reduce channel incision
- Enhance physical habitat structure of mainstem Sonoma Creek and its tributaries by increasing in-stream shelter, pools, and large woody debris
- Enhance summer baseflows
- Address fish barriers

We expect that watershed-based collaborative efforts, supported by incentive and funding programs, will accomplish many of the habitat enhancement actions needed to restore a healthy fishery. Sonoma Valley has a history of land stewardship, as evidenced by the fact that the watershed is still highly vegetated and forested. Groups and agencies such as the Sonoma Ecology Center, Parks Departments (State and County), RCD, and Sonoma County Water Agency have strong interest and history in implementing stream restoration, habitat enhancement, and landowner stewardship/education programs.

The limiting factors analysis and habitat surveys identify several restoration priorities and potential projects, and these recommendations provide a good foundation for further developing restoration and habitat enhancement projects. In addition, habitat enhancement holds many benefits beyond restoring a healthy fishery, including easing long-standing flooding problems and enhancing recreational values and tourism.

Preventing and Reducing Channel Incision

At this time we do not intend to propose a regulatory permitting program to require channel restoration and resolve the many adverse ecological and water quality impacts of channel incision. However, channel incision supplies more than half of the sediment load to Sonoma Creek, and much of the load is fine sediment. To achieve the TMDL, progress must be made in reducing sediment loads from channel incision.

Channel incision is a complex process, and solutions will require multiple approaches. We expect that existing and future permitting programs will help prevent additional incision as they require practices that will accelerate natural recovery (such as maintaining setbacks and preserving riparian corridors).

Existing channel incision must be addressed in a holistic way, on a reach basis, rather than property-by-property in most cases. Because stream processes work to balance energy, flow, and sediment, incision repair work on one bank or in one isolated section of a creek can have unintended and negative impacts on adjacent, crossbank, or downstream areas. Channel restoration must be done in a coordinated fashion, and it will be important to bring together all available technical expertise.

To control channel incision in a way that enhances habitat for fish and aquatic species, we recommend and support cooperative and coordinated actions by multiple landowners, planned and executed over significant distances along the river. To make efficient use of resources, projects should be planned and designed to provide multiple benefits, such as floodwater retention (by restoring floodplains), enhancing habitat (by encouraging pool formation), and bank stabilization. By creating stable banks, large-scale channel restoration project can also stabilize landslide areas and reduce sediment loads from landslides. Such large-scale, multi-benefit projects will be more competitive for grant funding as well as easier to manage.

The geomorphic analysis performed as part of the Sediment Source Analysis (SEC et al., 2006, Appendix C), should be used to guide channel restoration priorities. This analysis includes a map showing areas of high incision in the watershed, and estimates of percent fines in specific locations. This information could help to identify top priority sites for channel restoration.

Projects designed to Enhance Physical Habitat Structure

A high priority for restoring the steelhead fishery in Sonoma Creek is enhancing physical habitat structure, which would greatly increase the success of the juvenile rearing stage. (The need for enhancing physical habitat structure is also discussed in the Problem Statement section.) Enhancing physical habitat structure includes increasing: (1) riparian canopy; (2) large woody debris (both volume and frequency); and (3) frequency and depth of pools.

Increasing riparian canopy, in addition to providing shelter and food, would also help maintain suitable water temperatures by providing shade. Large woody debris (LWD) plays an important role in channel morphology by forming habitat such as pools, by storing sediment and organic matter, and by providing shelter. Habitat inventories performed in 1996, 2001-2002 and 2004-2006 document low amounts of large woody debris watershed-wide. These habitat inventories also document low frequency and quality of pool habitat.

We are confident that physical habitat enhancement can be successfully planned and implemented through collaborative stakeholder efforts, because of the accomplishments already achieved. There is already a complete habitat inventory of Sonoma Creek, as a result of the work of Sonoma Ecology Center, Southern Sonoma RCD, and the California Department of Fish and Game. The results of the habitat surveys have been analyzed to identify top restoration priorities. Queries have been performed on the habitat survey data to identify potential restoration sites for increasing riparian canopy, increasing scour depth and shelter in pools, and increasing pool connectivity (SEC, 2003; SEC, 2007).

We recommend that interested landowners, groups, and agencies—such as the Water Board, Parks departments, DFG, Sonoma Ecology Center, and the RCD work together to take the existing data and develop a prioritized restoration plan to address the physical habitat-related factors limiting the steelhead population. Interested groups could pull their resources together to provide technical expertise, assist with landowner education, and seek or provide funding.

Enhance Summer Base Flows

Many of Sonoma Creek's tributaries dry up in the summer, resulting in long reaches of dry stream and direct mortality to fish as pools dry up. Stranding by low flows (or no flow) has created the greatest source of mortality directly observed in the course of habitat surveys, with surveyors observing thousands of dead fry in dry pools (SEC et al., 2004).

We do not know of any major exports of Sonoma Creek water outside of the watershed. It is likely that in-watershed groundwater use, creek and stream diversions, and increased impermeable surfaces within the watershed have contributed to low summer flows. Enhancing summer base flows will require collaboration among many interests in the watershed. Two ways of increasing summer base flows are: 1) decreasing groundwater use, and 2) increasing groundwater recharge.

The Basin Advisory Panel, a collaborative group represented by local agriculture, government, business, dairies, and environmental interests, is developing the Sonoma Valley Groundwater Management Plan. The objectives of the plan include managing groundwater resources by: 1) maintain groundwater levels for the support of beneficial uses; 2) balance use of groundwater relative to other uses (i.e.., increase recycling and water conservation); and 3) identify and protect groundwater recharge areas and enhance the recharge of groundwater where appropriate (Sonoma County Water Agency website, http://www.scwa.ca.gov/projects/svgroundwater/management_plan.php)

We support and look forward to participating in collaborative efforts to conserve water and enhance groundwater recharge. One of the first steps may be to identify potential groundwater recharge areas and develop pilot projects.

Address Fish Barriers

Man-made barriers to fish passage prevent adult steelhead and Chinook salmon access to approximately 25 percent of the watershed stream length, according to the limiting factors analysis (SEC et al., 2004, Appendix J). The study identified 22 full barriers that cause an estimated 21,000 acres (170 miles of stream length) to be inaccessible to fish. In addition, there are 48 identified partial (flow-dependent) barriers (*ibid*.).

In the Sonoma Creek watershed, most barriers are due to road crossings and removing barriers can be achieved by retrofitting or replacing problem structures. Approaches for retrofitting culverts include reducing the height fish need to jump to enter the culvert, and increasing flow depths inside the culvert. During replacement of structures, guidance from DFG or FishNet 4C (FishNet 4C et al., 2004) should be followed to ensure that the new crossing is not a barrier to fish passage. High priority barriers for removal/replacement include those that have the best upstream habitat that would otherwise be available to fish, those where barrier removal is consistent with local management priorities, and barriers where removal is feasible and habitat disturbance can be minimized.

There exists in the watershed momentum and experience in fish passage barrier removal projects. Barrier removal projects are already being undertaken in the watershed. Sonoma Ecology Center has initiated barrier removal projects on Asbury, Mill, and Calabazas Creeks. In addition the Southern Sonoma Resource Conservation District has removed a partial barrier on Carriger Creek. Sonoma County also has an active program to make sure replacement structures are fish friendly (SEC et al., 2004).

To continue to make progress in removing fish passage barriers, we recommend a collaborative approach. The Water Board and other interested groups should work together to prioritize barrier removals, provide technical assistance, and provide or seek funding opportunities. Because Sonoma Creek is designated as a Critical Coastal Area[4], additional resources and funding may be available.

8.7 Evaluation and Monitoring

In collaboration with stakeholders in the watershed, Water Board staff will develop an evaluation and monitoring plan to assess progress of TMDL attainment and provide a basis for reviewing and revising TMDL elements or implementation actions. The plan may include:

[4] "The Critical Coastal Area (CCA) Program, part of the state's NPS Plan, is a non-regulatory planning tool to coordinate the efforts of multiple agencies and stakeholders, and direct resources to CCAs. The program's goal is to ensure that effective NPS management measures are implemented to protect or restore coastal water quality in CCAs. CCA identification supports the acquisition of grant funding by prioritizing protection efforts." –Critical Coastal Areas website: http://www.coastal.ca.gov/nps/Web/cca_project.htm

- Additional baseline monitoring to further characterize current conditions
- Implementation monitoring to ensure that identified actions, such as restoration projects or BMPs) are undertaken
- Effectiveness monitoring to assess whether actions are achieving water quality targets
- Trend monitoring to assess changes over time and progress (or lack of) towards identified water quality targets

8.8 Adaptive Implementation

As with all TMDLs, the Water Board will implement this project using an adaptive approach that allows us to add information and adjust our strategy based on new findings. The implementation plan included in the Basin Plan amendment will be regularly updated as progress is made and new information becomes available.

References

Citation in Text	Reference
ABAG, 2000	Association of Bay Area Governments. 2000. Bay Area Spatial Information Systems (BASIS) files for existing land use in 2000 for the San Francisco Bay Area (GIS layer). Oakland, CA. pp. ii, 5-6 (metadata files)
CDFG, 1998	California Department of Fish and Game. 1998. *California Salmonid Stream Habitat Restoration Manual*. 3rd edition, ed. by G. Flosi et. al. Sacramento, California: Fisheries Branch.
FishNet 4C et al., 2004	FishNet 4C, MFG, Inc., Prunuske Chatham Inc., and Pacific Watershed Associates. 2004. *Guidelines for Protecting Aquatic Habitat and Salmon Fisheries for County Road Maintenance*. Cotati, CA: FishNet 4C
Kondolf, 2000	Kondolf, G.M. 2000. "Assessing salmonid spawning gravel quality." *Transactions American Fisheries Society* 129:262-281.
Leidy et al., 2003	Leidy, R.A., G.S. Becker, and B.N. Harvey. 2003. *Historical Distribution and Current Status of Steelhead* (Oncorhynchus mykiss), *Coho Salmon* (O. kisutch), *and Chinook Salmon* (O. tshawytscha) *in Streams of the San Francisco Estuary, California*. Oakland, CA: Center for Ecosystem Management and Restoration.
Leidy, 2007	Leidy, R.A. 2007. *Ecology, Assemblage Structure, Distribution, and Status of Fishes in Streams Tributary to the San Francisco Estuary, California*. Oakland, CA: San Francisco Estuary Institute. Available online at http://www.sfei.org/leidy_No530/0_Cover_TableofContents.pdf Accessed 8/20/ 2007.
McCuddin, 1977	McCuddin, M.E. 1977. *Survival of salmon and trout embryos and fry in gravel-sand mixtures*. M.S. Thesis. University of Idaho, Moscow.
McNeil, 1964	McNeil, W.J. 1964. Effect of the spawning bed environment on reproduction of pink and chum salmon. *U.S. Fish and Wildlife Service Fishery Bulletin* 65: 495-523.
NCRWQCB, 2006	Regional Water Quality Control Board , North Coast Region. 2006. *Desired Salmonid Freshwater Habitat Conditions for Sediment-Related Indices*. Santa Rosa, California: NCRWQCB.
SEC et al., 2004	Sonoma Ecology Center, Stillwater Sciences, and UC Berkeley Department of Earth and Planetary Sciences. 2004. *Sonoma Creek Watershed Limiting Factors Analysis.* Eldridge, CA: SEC
SEC et al., 2006	Sonoma Ecology Center, Watershed Sciences, Martin Trso, Talon Associates LLC, and Tessera Consulting. 2006. *Sonoma Creek Watershed Sediment Source Analysis*. Sonoma, CA SEC

SEC, 2000	Sonoma Ecology Center. 2000. *Summary of Existing Information in the Watershed of Sonoma Valley in Relation to the Sonoma Creek Watershed Restoration Study and Recommendations in How to Proceed*. Eldridge, CA: SEC
SEC, 2002	Sonoma Ecology Center. 2002. *Oral History Project*. Eldridge, CA: SEC
SEC, 2003	Sonoma Ecology Center (SEC). 2003. *Sonoma Creek Stream Habitat Inventory Report on 2002 Survey, including Data from 1996 Survey*. Sonoma, CA: SEC
SEC, 2007	Sonoma Ecology Center. 2007. *Final Report Fish Habitat Inventory Sonoma Creek Watershed, California*. Eldridge, CA: SEC
SFBRWQCB, 2006	San Francisco Bay Regional Water Quality Control Board. 2006. *Water Quality Control Plan, San Francisco Bay Basin*. Oakland, California: SFBRWQCB
SFBRWQCB, 2007	Regional Water Quality Control Board, San Francisco Bay Region. 2007. *Napa River Watershed Sediment TMDL and Habitat Enhancement Plan*. *Proposed Basin Plan Amendment and Staff Report*. Oakland, CA: SFBRWQCB.
Sonoma County, 2001	Sonoma County Board of Supervisors. 2001. Article V. *Vineyard Erosion and Sediment Control Ordinance*. Sonoma County Code, Title 30, Article V. Available online at: http://www.sonoma-county.org/agcomm/vesco.htm Accessed August 20, 2007
Sonoma Valley Vintners and Growers Alliance, 2005	Sonoma Valley Vintners and Growers Alliance. 2005. *Interview Report on Best Management Practices in Sonoma Valley*. Prepared by: The Southern Sonoma County Resource Conservation District. Petaluma, CA: The Southern Sonoma County Resource Conservation District
SSRCD, 1996	Southern Sonoma Resource Conservation District. 1996. *Sonoma Creek Habitat Inventory*. Petaluma, CA: SSRCD.
State Board and California Coastal Commission, 2000	State Water Resources Control Board (SWRCB) and California Coastal Commission. 2000. *Plan for California's Nonpoint Source Pollution Control Program*. Sacramento, California: SWRCB
State Board, 2004	State Water Resources Control Board. 2004. *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*. Sacramento, California: California Environmental Protection Agency
Stillwater Sciences and Dietrich, 2002	Stillwater Sciences and W.E. Dietrich. 2002. *Napa River Basin Limiting Factors Analysis*. Final Technical Report prepared for San Francisco Bay Regional Water Quality Control Board and California State Coastal Conservancy. Oakland, CA: SFBRWQCB.

Sullivan et al., 2000	Sullivan, K., Martin, D.J., Cardwell, R.D., Toll, J.E., and Duke, S. 2000. *An analysis of the effects of temperature on Salmonids of the Pacific Northwest with Implications for selection temperature criteria*. Portland, Oregon: Sustainable Ecosystems Institute.
Taggart, 1976	Taggart, J.V. 1976. *The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington.* Master's thesis. University of Washington, Seattle
U.S. EPA, 1991	U.S. Environmental Protection Agency, 1991. *Guidance for water quality-based decisions: The TMDL process.* EPA publication 440/4-91-001. Washington, D.C.: Assessment and Watershed Protection Division.
U.S. EPA, 1999	U.S. Environmental Protection Agency. 1999. *Protocol for Developing Sediment TMDLs*. First edition. EPA publication 814-B-99-004. Washington, D.C.: Office of Water, pp. 7-1—7-7
UC Berkeley Extension, 2001	University of California Berkeley Extension. 2001. "Summary of Sonoma County Policies Relating to Anadromous Fish Habitat Conservation." Excerpted from *Effects of County Land Use Policies and Management Practices on Anadromous Salmonids and Their Habitat*. Berkeley, CA: UC Berkeley Extension
University of California, 2002	University of California. 2002. *California guidelines for residual dry matter (RDM) on coastal and foothills annual rangelands*. University of California, Division of Agriculture and Natural Resources, Rangeland Monitoring Series Publication 8092. University of California, Davis. Available online: http://californiarangeland.ucdavis.edu/Publications%20pdf/8092.pdf. Accessed 8/22/2007